Theory of . . .

INSTRUMENT FLYING

DEPARTMENT OF THE AIR FORCE

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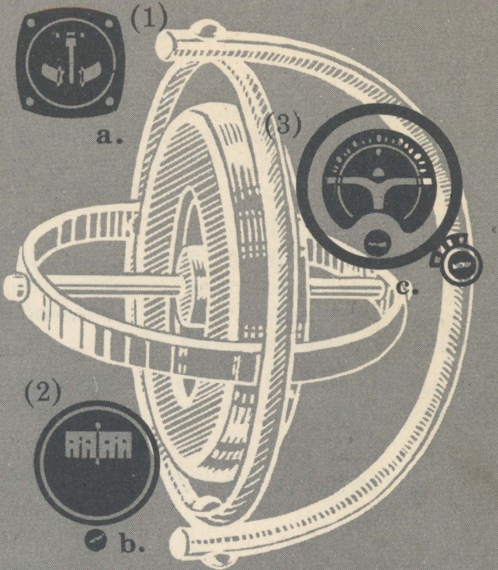

Theory of . . .

INSTRUMENT FLYING

DEPARTMENT OF THE AIR FORCE

AIR FORCE MANUAL
NO. 51-38A

DEPARTMENT OF THE AIR FORCE
WASHINGTON, APRIL 1952

FOREWORD

1. PURPOSE AND SCOPE. This Manual on theory of instrument flying is published for use of instructors at the instrument, basic flying, and advanced flying schools, and for the information of all Air Force pilots. The main topics considered are basic aircraft control and instrument interpretation, basic radio, and weather.

2. RECOMMENDATIONS. Recommendations or suggestions for the improvement of instrument flying techniques and procedures or of this manual are encouraged. Comments may be forwarded to Director of Training, Headquarters USAF, Washington 25, D. C.

3. CHANGES. AF Manual 51-38 has been changed as follows: Chapters 23, 37 and 42 have been changed as of April 1952.

BY ORDER OF THE SECRETARY OF THE AIR FORCE:

HOYT S. VANDENBERG
Chief of Staff
United States Air Force

OFFICIAL:
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INTRODUCTION

During the years between 1930 and 1944, aircraft progressively became larger and more complex until the large bombers and transports could no longer be flown by "feel" or by "the seat of the pants," even in the clearest weather. There was little need or desire for the Air Force pilot to fly in weather. As a matter of fact, the student was continually warned against the dangers of weather flying. When the student graduated he had little desire for or ability in instrument flying.

Soon after December 7, 1941, the Air Force found through hard and costly experience that little had been written about instrument flying, and less had been done to improve the instrument flying technique of the Air Force pilot. As the war progressed, such things as tremendous weight, high speeds, positions of the pilot and co-pilot, etc., made it impossible to fly military aircraft safely by "feel" alone. It became necessary to make frequent reference to the flight instruments to determine the aircraft's attitude and performance.

At the beginning of this period of expansion (December 7, 1941), the Army Air Force was using a system known as the 1-2-3 or "needle-ball-air speed" system, devised and written in 1930 as a technical manual. This system was the best that could be devised for the type of aircraft in operation during 1930, but it was completely inadequate for the large bombers and transports of 1941. No consideration was given to such instruments as the artificial horizon and directional gyro. Other inadequacies of the system were: (1) It was absolutely mechanical. (The technical manual plainly stated that the rudder controls the needle, ailerons control the ball, and the elevators control the air speed.) (2) It did not make profitable use of the pilot's ability to fly by visual references. (3) It discouraged close coordination of the controls.

When the United States entered the war, the instrument requirements for a pilot were 15 to 20 hours of instruction on this 1-2-3 system. There was little or no organization in the presentation of these valuable hours to be devoted to instrument flying. Instrument training was a drudgery to the instructor, and often instrument time was logged in the Form 1 but was not actually flown. An instrument ride often gave opportunity to the instructor to show the student several "tricks," or brush up on his acrobatic proficiency. This disinterest in instrument flying had to be turned into enthusiasm by furnishing the instructor and student with something new, interesting, and sound in principle.

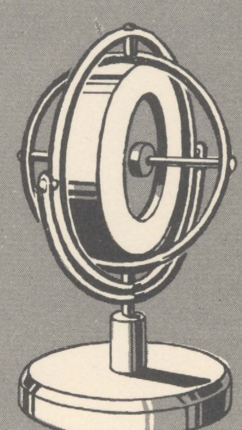
During 1941 and 1942, regulations permitted instrument checks to be taken in a Link trainer. It is not a secret that a satisfactory orientation and beam problem was conclusive evidence that a pilot had earned an instrument rating. Regulations at that time also permitted any pilot who held a current instrument rating, regardless of how it was obtained, to check another pilot and issue him an instrument rating. Instrument flying and training were not progressing with types of missions and aircraft to be flown. As a result of the standstill of training and the swift advance of operational requirements, it may be said that instrument training was actually deteriorating at that time. The number of lives lost and aircraft wrecked because of faulty instrument flying during that period was ample evidence that a more up-to-date and effective instrument flying system and training program were necessary.

In the spring of 1942, Colonel J. B. Duckworth, then Director of Training at Columbus, Mississippi, realizing that the Columbus Advanced Flying School was not graduating qualified instrument pilots, obtained the sanction of the Commanding General of the Eastern Flying Training Command and began looking for a sound remedy to this situation. Material on the subject of instrument flying was collected from the Air Corps, Navy, Airlines, and any other source available. Tests were given to learn what instructors, supervisory personnel, and students actually knew about instrument flying. The average grade on these tests for 64 rated pilots was 57 per cent. While material was being collected, sorted, and tested, a new system of full-panel attitude instrument flying was devised. After exhaustive tests and plans were carried out, it was found that this new system was much more adequate and effective than the other system. Thus, the full-panel system of attitude instrument flying was born and incorporated into the training programs of the Army Air Force during the early part of 1943.

CONTENTS

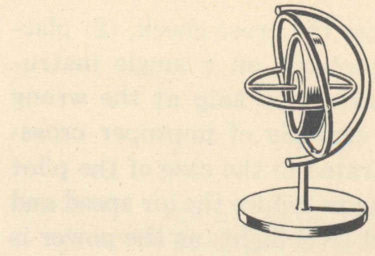
Part 1

Basic Aircraft Control and Instrument Interpretation



Outline to Part 1

CHAPTER ONE



Attitude Instrument Flying

The attitude of an aircraft is the relationship of its longitudinal axis (or fuselage), its lateral (or wings), and the earth's surface or any plane parallel to the earth's surface. Attitude instrument flying is controlling the attitude of an aircraft by reference to instruments.

Attitude instrument flying is similar to visual flying in that reference points are used to determine the attitude of the aircraft in both methods. While flying by visual reference to the earth's surface the pilot determines the attitude of the aircraft by observing the relation between the aircraft's nose and wings and the natural horizon. The pilot while flying by reference to flight instruments determines the attitude of the aircraft by observing indications on the instruments which give him essentially the same information obtained by visual reference to the earth's surface. Another similarity between attitude instrument flying and visual flying is the manner in which the aircraft is controlled. The pilot uses exactly the same control techniques while flying by reference to instruments as he does in visual flying. The student of attitude instrument flying, therefore, is not required to learn a different method of controlling the aircraft which was true of some of the other methods of instrument flying. The largest single learning factor of attitude instrument flying is that of using the flight instruments to determine the attitude of the aircraft.

THREE COMPONENTS OF ATTITUDE INSTRUMENT FLYING

Attitude instrument flying consists of three major components: (1) instrument coverage (cross-checking), (2) instrument interpretation, and (3) aircraft control.

Instrument Coverage

Instrument coverage is commonly termed "cross-checking." Experiments on cross-checking have shown that a pilot whose instrument flying proficiency is at a high level looks at each instrument much more often than does the pilot whose proficiency is at a lower level. Many times, the lack of precision in instrument flying can be traced to slow and inaccurate cross-checking which can best be improved and perfected by practice and experience. Common faults in instrument cross-checking are: (1) omitting an instru-

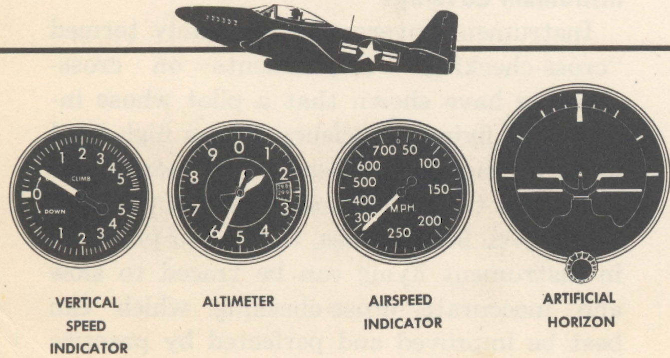
ment entirely from the cross-check, (2) placing too much emphasis on a single instrument, and (3) gazing too long at the wrong instrument. An example of improper cross-checking is illustrated in the case of the pilot who is attempting to reduce the air speed and hold straight-and-level flight; as the power is reduced he observes the manifold pressure gage closely so as to make the proper adjustments and neglects to observe the instruments that give indications of a deviation from straight-and-level flight. This failure to observe the proper instruments sufficiently could very well be the underlying cause for a poorly executed maneuver of this sort. There is no one set order to follow while cross-checking the instruments. The order of checking depends upon the type of maneuver to be executed. During certain maneuvers, one instrument or group of instruments may be of prime importance; during other maneuvers, other instruments may be of prime importance.

Instrument Interpretation

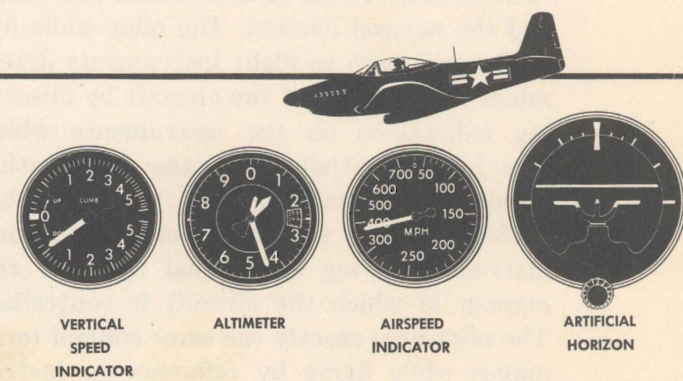
The second major component in attitude instrument flying is instrument interpretation which experience has shown is the most difficult to learn. Proper instrument interpretation contributes to efficient instrument flying techniques. Some instruments, because of their facial design, are very difficult to interpret. Precision instrument flying is impossible if the instruments are not interpreted properly; therefore, the student should apply himself fully in order to attain the desired precision. He should consider this component learned only when each instrument indication can be interpreted in terms of the attitude of the aircraft. The first step in becoming proficient in instrument interpretation is learning the construction and principle of operation of each flight instrument. This reduces the difficulty of learning to use the instruments and usually results in higher standards of proficiency. If the position of the wings is to be determined, the indications of the artificial horizon, the directional gyro, and the needle and ball must be interpreted. If the position of the nose is to be determined, the air-speed indicator, the altimeter, the vertical-speed indicator, and the artificial horizon must be interpreted. The indications on the flight instruments should be interpreted in terms of the attitude of the aircraft at all times.

Aircraft Control

The third and final component of attitude instrument flying is aircraft control. During



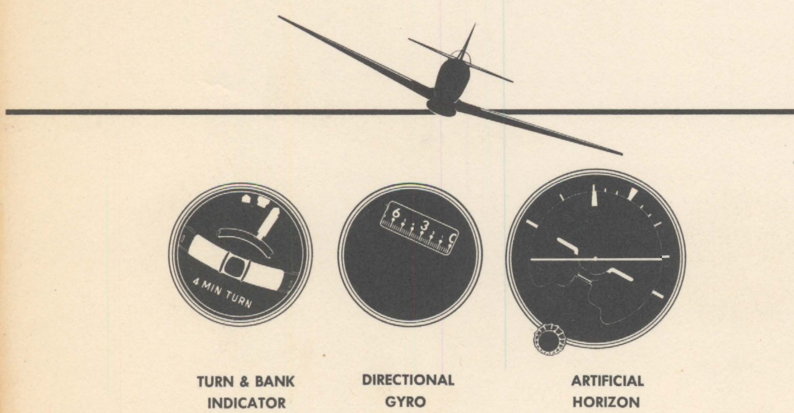
Instruments interpreted in a climb.



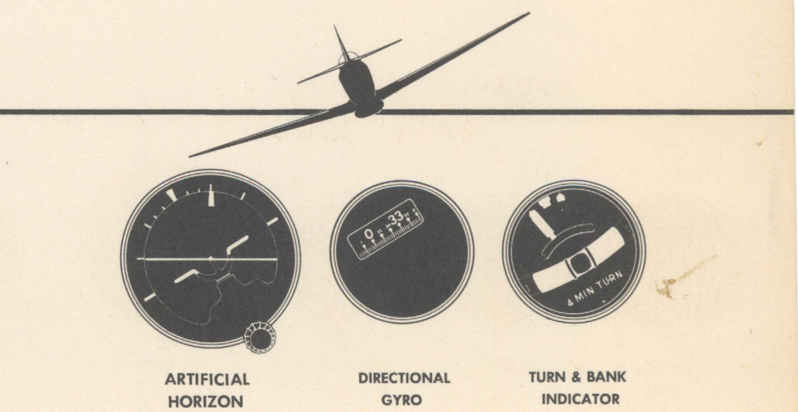
Instruments interpreted in a descent.

his first flying instruction, a student is taught to notice the appearance of the actual horizon in its relation to the wings or some other reference point on the aircraft. He pictures the appearance of the aircraft's nose on the horizon in a climb and the angle the wings make with the horizon in a steep bank. His control movements are a result of responses to changes in the attitude of the aircraft. During this early training period, the natural horizon and reference points on the aircraft are the student's "instruments." Before he moves the controls of the aircraft, he must read the attitude of the aircraft from these "instruments" so that he will know what control pressures to use. He then coordinates the controls to place the aircraft in the desired position. Correct control pressures are used because in all of his visual flying, the relation between control movements and aircraft attitude has been emphasized very strongly by the instructor. Instrument flying, then, is essentially visual flying; the instruments (airspeed indicator, altimeter, turn and bank indicator, artificial horizon, directional gyro, and vertical-speed indicator) are substituted for the earth's surface and various points on the aircraft which are used in visual flight. Control movements necessary to produce a given attitude by reference to instruments are the same as used in visual flight, and the same is true of the thought processes. If a pilot has good instrument flying techniques and abilities in one aircraft, he can fly by instruments satisfactorily in any type of aircraft in which he has attained adequate flying proficiency.

Aircraft control is broken down into four coordinated steps: (1) pitch control, (2) bank control, (3) power control, and (4) trim. Pitch control is achieved by controlling the movement of the fuselage about the lateral (wing) axis which is accomplished by movements of the elevators. After interpreting the pitch attitude of the aircraft from the proper flight instruments, control pressures are exerted on the elevators to effect the desired pitch attitude with reference to the earth's surface. Bank control is achieved by controlling the angle made by the wing and the earth's surface or the movement of the wings about the longitudinal axis (fuselage). After interpreting the bank attitude from the proper instruments, the necessary control pressures are exerted to attain the desired bank attitude. Power control, which is the control of the power plant of the aircraft, is used to achieve the desired air speeds and flight path. Trim control is achieved by relieving all possible control pressures after the desired attitude has been attained. Precision



Instruments interpreted in a right turn.



Instruments interpreted in a left turn.

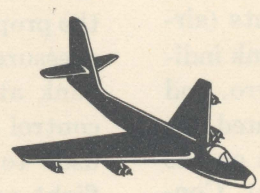
instrument flying is very difficult when pressures must be held manually to achieve and hold a desired attitude; therefore, trim control must be exercised to relieve as many control pressures as possible. Pitch, bank, power, and trim control are performed in a coordinated manner, and the breakdown shown here is only an analytical treatment of the subject of aircraft control.

Relaxation

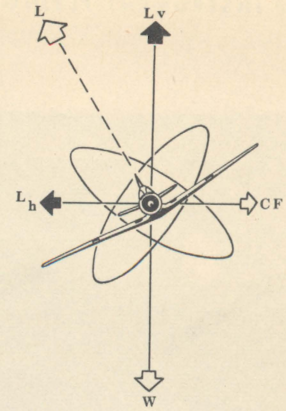
Much has been said about relaxation while flying by reference to instruments, and it is mentioned here to serve as a reminder only. Good instrument flying techniques are difficult to employ when the individual is tense. Tenseness results when maneuvers and procedures are executed require much activity. It can be detected when control movements are erratic and abrupt, and when pressures are held on the controls in opposition to the trim. A suggested procedure to overcome tenseness is to hold the controls lightly and trim the aircraft to maintain the desired attitude.

Summary

Instrument flying has become of age in the Air Force. The pilot who is not proficient in attitude instrument flying is a limited pilot and there must be no such pilots in the Air Force if it is to be effective as an all-weather striking force. The attitude instrument flying method is not completely adequate in its present state because of the rapid advance in aircraft in recent months; because of its soundness in principle, however, the system can be made adequate for present-day jet aircraft and present-day operational requirements within a short interval of time.



CHAPTER TWO



Applied Aerodynamics

Proficiency in attitude instrument flying can be expected sooner if the student has a complete understanding of the theory of flight. He should have a good general knowledge of aerodynamics. Aerodynamics is a branch of dynamics. It may be thought of as the resultant mechanical effects of air (or other gases) under the action of force.

If a flat plate is moved through the air as illustrated in Figure 1, the air stream which strikes the plate is given a downward force by the impact against the plate. The reaction to this downward force produces a resultant force up and back which creates lift and drag.

The air flow through a Venturi tube is speeded up, and the air pressure within the tube is reduced (Bernoulli's theorem). Similar reactions occur to the upper surface of the wing (airfoil) since it acts as the lower half of a Venturi tube. Because of the reduced pressure above the wing and the reactive force exerted on the underside, the "resultant aerodynamic force" is formed. (See Figure 2.)

Relative Wind

The relative wind in aerodynamics is the motion of the air relative to the airfoil. The air can be moving past the airfoil or the airfoil can be passing through the air. The relative wind is parallel and opposite the flight path of the aircraft.

The Angle of Attack

The angle of attack is the acute angle measured between the chord of the wing and the relative wind. The chord line of an airfoil is merely a conveniently chosen reference line in the wing. It measures the real or theoretical width of the wing. The angle of attack is *not* the angle measured between the chord of the wings and the earth's surface.

Lift

In understanding the relation between the forces acting on the aircraft, the attitude, and the control pressures, the instrument pilot should know the nature of these forces, factors determining them, and how they can be controlled and changed to produce the desired reaction of the aircraft.

The resultant aerodynamic force is created as a result of the motion of the air about an airfoil. This force is normally resolved into two components for aerodynamic analysis. These components are termed "lift" and

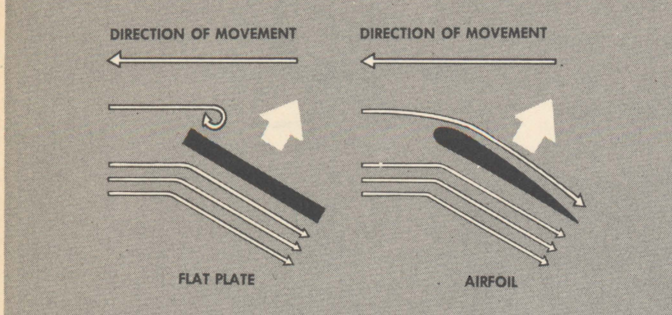


Figure 1. Movement of flat plate and air foil.

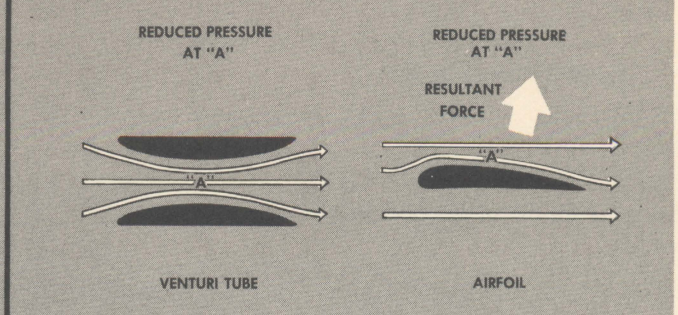


Figure 2. Resultant force.

"drag". The force of lift always acts in a direction perpendicular to the relative wind and to the lateral axis of the aircraft (wing-tip to wing-tip axis). Its direction relative to the earth's surface can be changed by banking the aircraft or entering climbs and descents. The magnitude of the force of lift is directly proportional to the density of the air, the area of the wing, and the air speed. It also depends upon the type of wing and the angle of attack. Lift increases with an increase in the angle of attack up to the stalling angle, at which point it will decrease with any further increase in angle of attack. The amount of lift can be controlled by varying any of the above mentioned factors. See Figure 3 for a diagram of the lift force acting on an airfoil.

Drag

Drag is the total resistance of the air to the passage of the aircraft through it. Drag acts in a direction to the rear of the aircraft and is parallel to the relative wind. Induced drag is a component of the resultant aerodynamic force. Parasite drag is drag caused by the disruption of the streamline air flow, skin friction and various minor projections extending into the air stream. Total drag is the sum of the induced drag and the parasite drag. The magnitude of induced drag as produced by the wing is dependent on the same factors as lift. Parasite drag depends upon air speed and air density as well as those factors that cause skin friction, etc. Parasite drag can be increased by extending the landing gear, opening the bomb bay doors, etc. Flaps are known as high lift devices, but, inasmuch as an increase in lift results in an increase in induced drag, flaps also increase the drag considerably. This increase in lift and drag facilitates steeper gliding angles and lower landing speeds. The ability to increase drag is important at many times for the instrument pilot. See Figure 3 for diagrams of wing drag.

Thrust

Thrust is the forward pull created by the propeller and its resulting slip stream. In the case of thermal-jet aircraft, thrust is the reaction to the rearward emission of gases through the tailpipe. The amount of thrust depends upon the power output of the engine under consideration and acts, for all practical purposes, parallel to the longitudinal axis of the aircraft. With thrust the pilot can control the air speed and flight path of the aircraft.

Weight

Weight is the force of gravity acting on the aircraft and its cargo. Its direction of force is always toward the center of the earth and does not change even though the aircraft changes attitudes and flight paths. Its magnitude, which depends upon the mass of the aircraft and its cargo, is changed by consuming fuel,

dropping bombs, etc. We shall consider the force of weight as a constant for any given problem and as acting from a point on the aircraft called the center of gravity.

STRAIGHT-AND-LEVEL FLIGHT

In every condition of flight the forces acting on the aircraft will have a definite relationship. Such is true of straight-and-level flight where weight acts downward toward the center of the earth; lift acts perpendicular to the relative wind and is equal and opposite to weight; drag acts parallel to the relative wind and to the rear; and thrust acts forward and parallel to the longitudinal axis and is equal and opposite to drag. Thrust in this case is considered as acting along the flight path.

Air Speed

At slow air speeds the angle of attack of an airfoil must be relatively large to produce the constant lift necessary to maintain level flight. As a result the aircraft must be flown in a nose-high attitude. As power is increased and the aircraft is accelerated, the nose must be lowered, because the angle of attack necessary to produce sufficient lift to maintain level flight will become smaller. Remember, any change in air speed requires a change in attitude to maintain straight-and-level flight.

Air Density

The density of the air decreases with increases in either altitude or air temperature. To maintain a given amount of lift the angle of

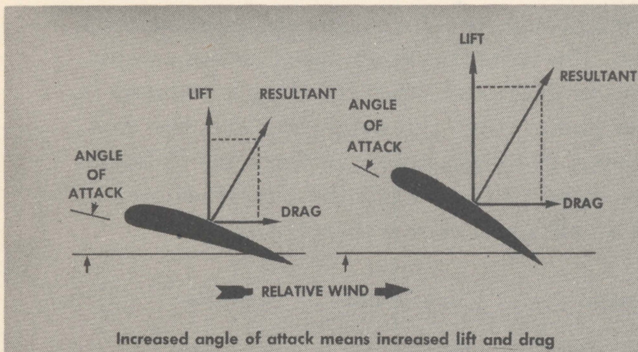


Figure 3. Lift and drag of wing.

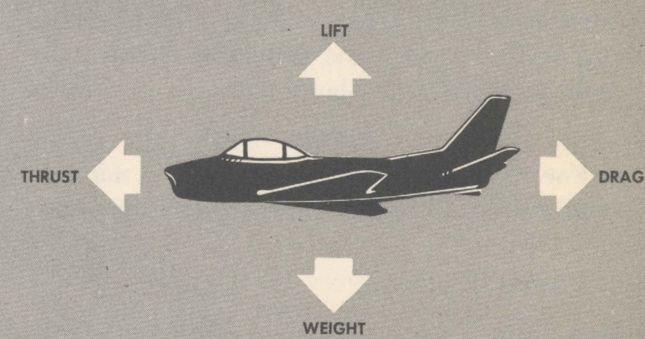


Figure 4. Forces on aircraft, straight and level flight.

All these forces must be balanced for straight-and-level, unaccelerated flight. See Figure 4 for a diagram of the forces acting on the aircraft in straight-and-level flight.

FACTORS AFFECTING ATTITUDE IN STRAIGHT-AND-LEVEL FLIGHT

As previously stated, attitude is the relationship of the longitudinal axis and the lateral axis of the aircraft to the horizontal reference plane (earth's surface). It should not be confused with either the flight path or the angle of attack. Figure 5 illustrates the attitude of an aircraft. In maintaining straight-and-level flight, three factors affect attitude; air speed, air density, and the weight of the aircraft.

attack of an airfoil must be increased as the density of the air decreases. Therefore, in order to maintain level flight at high altitudes or in regions of very warm, free-air temperatures, the attitude of the aircraft must be relatively nose-high.

Weight of The Aircraft

At normal weight an aircraft requires a definite angle of attack to maintain straight-and-level flight at a given air speed. However, to sustain a heavier load at the same air speed, the angle of attack of the airfoil must be greater to provide the increased lift necessary. Also more power must be added to overcome the increased drag resulting from the increased

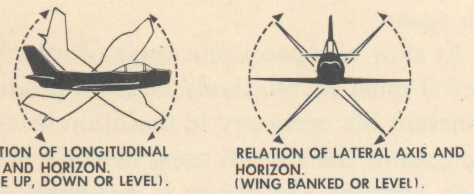


Figure 5. Attitude of an aircraft.

angle of attack if the same air speed is to be maintained. For example, at the start of a bombing mission an aircraft must be flown in a slightly nose-high attitude in order to maintain level flight, and as the bomb and fuel loads are expended, the nose of the aircraft must be lowered to maintain level flight.

Since air speed, air density, and load vary, the pilot must learn the correct attitude required under different conditions from experience with each particular type of aircraft. Figure 6 illustrates the factors affecting attitude in straight-and-level flight.

CLIMBS

For all practical purposes the lift in normal climbs is the same as in level flight at the same

toward a higher altitude. The flight path is then inclined upward and as a result, the angle of attack and the corresponding lift again stabilize.

As the climb is started, the air speed gradually diminishes. This change in air speed is gradual rather than immediate because of the momentum of the aircraft. The thrust required to maintain straight-and-level flight at a given air speed is not sufficient to maintain the same air speed in a climb. This is due to a component of weight acting in the same direction and parallel to the total drag of the aircraft so that thrust must equal the total drag of the aircraft plus the component of the weight. Therefore, as the aircraft enters into a climb and the power remains the same as in straight-and-level flight, the air speed becomes less. The reduction in air speed causes a reduction in drag, and when the drag is reduced to the point where the total drag and the component of weight acting in the same direction are equal to the thrust, the aircraft climbs at at an air speed slower than cruising.

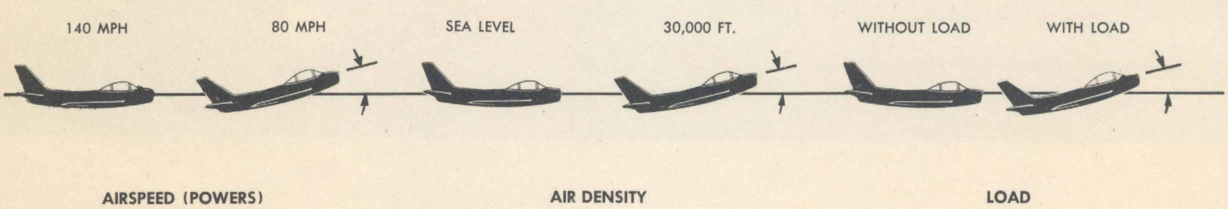


Figure 6. Factors affecting attitude.

air speed, because the angle of attack of the airfoil with respect to the flight path remains the same regardless of any variation of the flight path from the horizontal. In going from straight-and-level flight to a climb, the forces acting on the aircraft go through definite changes with the change in attitude. The first change, lift, occurs when back pressure is applied to the controls. The change in lift is a result of the change in the angle of attack which occurs when the nose is raised. Momentarily the lift, which becomes greater than the weight of the aircraft, forces it upward

To go from level flight into a climb of the same air speed, the pilot must increase the power output (thrust) of the engine. This is necessary because of the additional thrust necessary to overcome the component of weight acting in the same direction and parallel to the total drag of the aircraft.

Lift is equal in magnitude to the component of weight that is perpendicular to the flight path. In a climb, a component of weight acts to the rear and parallel to the total drag of the aircraft; and is balanced by a part of the thrust. For normal rates of climb this com-

ponent of weight is not very much since the angle of attack changes very little. It is important in aircraft which climb at large angles of attack. Figure 7 illustrates the forces acting on the aircraft in a climb.

DESCENTS

As in climbs, the forces acting on the aircraft go through definite changes when a descent is entered from straight-and-level flight. The first analysis is that of descending at the same power as used in straight-and-level flight. When forward pressure is applied to the controls, the angle of attack is reduced and, as a result, the lift of the airfoil is reduced. This reduction in lift is momentary, because as in climbing flight, the flight path changes and the angle of attack resumes the value of the straight-and-level condition. The change in the flight path is due to the fact that the lift becomes less than the weight of the aircraft as the angle of attack is reduced. This unbalance of lift and weight causes the aircraft to follow a descending flight path with respect to the horizontal flight path of straight-and-level flight. As the flight path changes to a descent, the angle of attack of the airfoil will again approach the original value and lift and weight stabilize. As the descent is started, the air speed will gradually increase. This is due to a component of weight now acting forward along the flight path. The overall effect is that of increased power or thrust, which in turn causes the increase in air speed associated with descending at the same power as used in level flight.

For descents at the same air speed as used in straight-and-level flight, obviously, the power must be reduced as the descent is entered. The component of weight acting forward along the flight path will increase as the rate of descent increases and conversely, will decrease as the rate of descent decreases. Therefore, the amount of power reduction for a descent at the same speed as cruise will be determined by the rate of descent desired.

VERTICAL-SPEED CHARACTERISTICS FOR CLIMBS AND DESCENTS

For a given attitude, the vertical speed is greater at higher air speeds than at lower air speeds. A small change in attitude results in large changes in the vertical-speed indications at high speeds and will result in smaller changes at lower speeds. For any given change in attitude under normal conditions, the vertical speed is directly proportional to the air speed. This is true for both climbs and descents. An analogy of this occurs when two automobiles travel 60 and 30 mph respectively and climb a hill which rises 500 feet in each mile. The automobile going 60 mph will climb 500 feet each minute, and the automobile going 30 mph will climb 250 feet each minute. Figure 8 illustrates the effect of air speed on vertical speed. The vertical speed characteristics are the same for both climbs and descents, therefore, only climbs are illustrated.

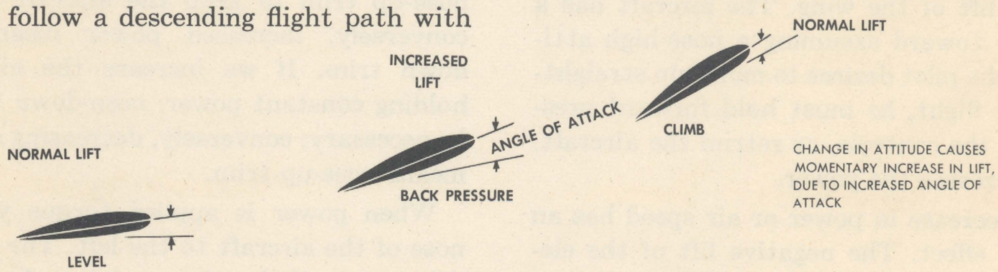


Figure 7. Climbing flight.

ELEVATOR ACTION WITH CHANGING POWER AND AIR SPEED

Raising and lowering the nose of the aircraft has been referred to many times in straight-and-level flight, climb, and descent analysis. The raising and lowering of the nose of the aircraft is made possible by the use of the elevators; therefore, a few points are provided here to aid in understanding pitch

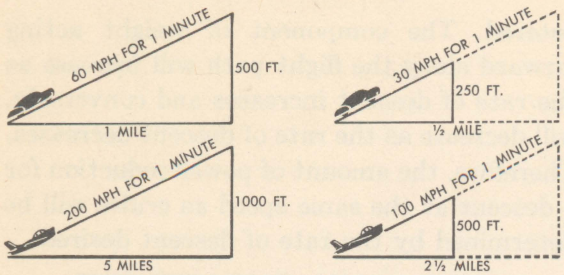


Figure 8. Vertical speed versus air speed in climbs.

control. The use of the elevators differs with any change in power and air speed. The slip stream striking the elevators in a downward direction creates a negative angle of attack for the elevator. A negative lift, therefore, is exerted by the elevators.

Changing power and air speed will change the amount of downwash and the resulting amount of negative lift exerted by the elevator. As power and air speed increase, downwash and slip-stream velocity increase, thereby increasing the negative lift on the elevator and the lift of the wing. The aircraft has a tendency toward assuming a nose-high attitude. If the pilot desires to maintain straight-and-level flight, he must hold forward pressures on the controls, or retrim the aircraft, as he increases the power.

Any decrease in power or air speed has an opposite effect. The negative lift of the elevators and the lift of the wing decrease, and the result is a tendency of the aircraft to assume a nose-low attitude. It is then necessary to hold back pressures on the controls or retrim the aircraft as the power or air speed is reduced.

TRIM CHARACTERISTICS WITH CHANGING POWER AND AIR SPEED

There are two additional items about lift and weight that are important in instrument flying. Weight always acts through a point in the aircraft called the center of gravity. This point is always on the center line of the aircraft and slightly behind the leading edge of the wing. Lift always acts through a point called the center of pressure which is located in the aft portion of the wing chord behind the center of gravity. Since these two points do not coincide, a twisting force is exerted on the aircraft by the forces of lift and weight. The result is a normal nose heaviness. This twist is balanced by the negative lift produced by the horizontal stabilizer and elevator surfaces. The amount of negative lift produced by the elevators is dependent on the air speed and power. From this we can see that if we reduce power with a constant air speed, we decrease this negative lift and must use nose-up trim to keep the aircraft in trim; conversely, increased power means nose-down trim. If we increase the air speed, holding constant power, nose-down trim will be necessary; conversely, decreasing air speed means nose-up trim.

When power is applied torque yaws the nose of the aircraft to the left. The same result occurs if the air speed is reduced while the power remains constant. Torque is overcome by the rudder in essentially the same manner as the natural nose heaviness of the aircraft is overcome by the elevators and the horizontal stabilizer. The force on the rudder

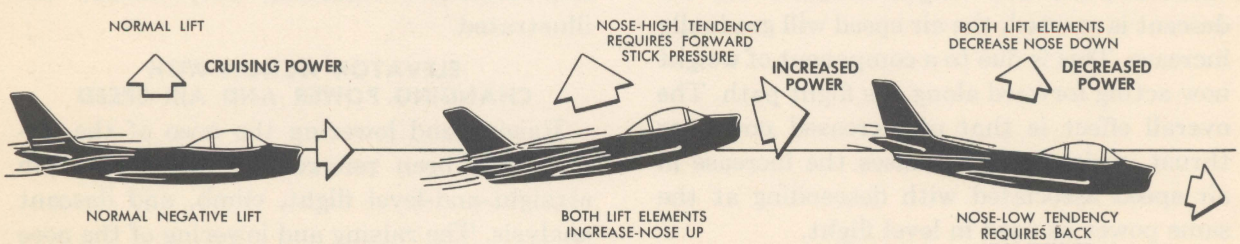


Figure 9. Changing power and attitude.

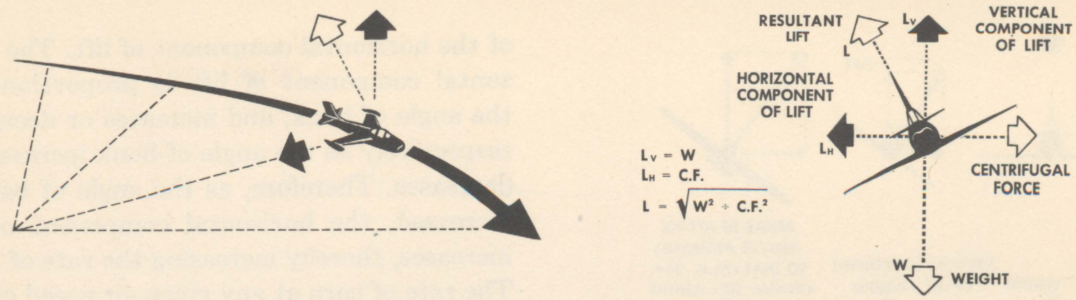


Figure 10. Forces acting on aircraft in normal turn.

depends on the control setting and the air flow. The air flow depends on the air speed and the slip-stream velocity. Torque is a force and increases with power. The following rule helps in trimming an aircraft to correct for torque effects. If power is reduced (air speed constant), left rudder trim must be added, and, conversely, if power is increased (air speed constant), right rudder trim must be added; if air speed is decreased (power constant), right rudder trim must be added, and, conversely, if air speed is increased (power constant), left rudder trim must be added. Figure 9 illustrates effects of changing power on attitude.

TURNS

A pilot who understands the forces acting on an aircraft in a turn and knows how to bring these forces to bear upon the aircraft should have no difficulty with directional control. The misconceptions in the minds of many pilots as to the manner in which an aircraft is turned have been partially responsible for the faulty manner in which instrument flying has been taught. If an aircraft were viewed in straight-and-level flight from a head-on view, and if the forces acting on the aircraft could actually be seen, two forces, lift and weight, would be apparent; and, if the aircraft were in a bank it would be apparent that lift did not act opposite to the weight. The fact that lift acts inward toward the center of the turn as well as upward is one of the basic facts to remember in consideration of turns. This fact should help to eliminate many misconceptions regarding turns.

Forces Acting On An Aircraft In Turns

An aircraft, like any moving object, requires a sideward force to make it turn. In a normal turn, this force is supplied by banking the aircraft so that lift is exerted inward as well as upward. The force of lift in a turn is separated into two components at right angles to each other. One component which is drawn vertically and opposite to weight is called the "vertical component of lift." The other which is drawn horizontally toward the center of the turn is called the "horizontal component of lift." The horizontal component of lift is the force that causes the aircraft to turn. Centrifugal force is the equal and opposite reaction of the aircraft to the change in direction and is equal and opposite to the horizontal component of lift. In a correctly executed turn, the force to turn the aircraft is not supplied by the rudder. An aircraft is not steered like a boat or an automobile; in order to turn, it must be banked. If the aircraft is not banked, there is no force available that will cause it to deviate from a straight flight path, provided it is not skidding. Conversely, when an aircraft is banked, it will turn, provided it is not slipping. Good directional control is based on the fact that the aircraft will turn if banked. This fact should be borne in mind at all times while attempting to hold the aircraft straight and level by reference to instruments. An indication of a bank from the flight instruments, should immediately be corrected by a roll-out of the bank in order to maintain the desired heading and flight path. Figure 10 illustrates the forces acting on an aircraft in a normal turn.

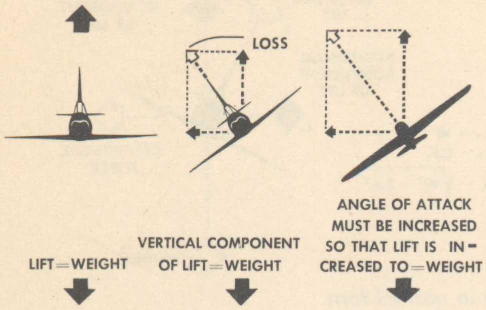


Figure 11. Loss of vertical lift while entering turn.

Changes In Lift In A Turn

Banking the aircraft in order to turn produces no change in the amount of lift. In a bank, however, the lift is divided into two components, one vertical and the other horizontal. This division reduces the amount of lift which is supporting the weight of the aircraft; consequently, the aircraft loses altitude unless the total lift is increased by increasing the angle of attack until the vertical component of lift is equal to the weight. The vertical component of lift decreases as the angle of bank is increased and, as a result, the angle of attack must be increased as the angle of bank is increased in order to produce sufficient vertical lift to support the weight of the aircraft. The fact that the vertical component of lift must be equal to the weight for a correctly executed level turn is an important fact to remember when making turns. Figure 11 illustrates the loss of vertical lift while entering turns.

Angle of Bank Versus Rate of Turn

At a given air speed, the rate at which an aircraft turns depends upon the magnitude of the horizontal component of lift. The horizontal component of lift is proportional to the angle of bank, and increases or decreases respectively as the angle of bank increases or decreases. Therefore, as the angle of bank is increased, the horizontal component of lift increases, thereby increasing the rate of turn. The rate of turn at any given air speed can be controlled by the angle of bank. Figure 12 shows how, in a correctly executed turn at a constant air speed, the aircraft will turn more rapidly as the angle of bank is increased.

The Increase of Drag In A Turn

The increase of the total lift required to hold altitude in a level turn requires an increase in the angle of attack. The drag of the airfoil is directly proportional to the angle of attack, and consequently, the drag increases as the lift is increased. This results in a loss of air speed in a turn which is proportional to the angle of bank; a small angle of bank results in a small reduction in air speed and a large angle of bank results in a large reduction in air speed. Additional thrust (power) must be added to prevent a reduction in air speed in level turns and the amount of additional thrust required is proportional to the angle of bank.

Executing Turns At A Constant Rate

If the air speed is increased in a turn, the angle of attack must be decreased or the angle of bank increased if a constant altitude is to be maintained. If the angle of bank is held constant and the angle of attack is decreased, the rate of turn decreases. Therefore, in order to maintain a constant rate of turn as

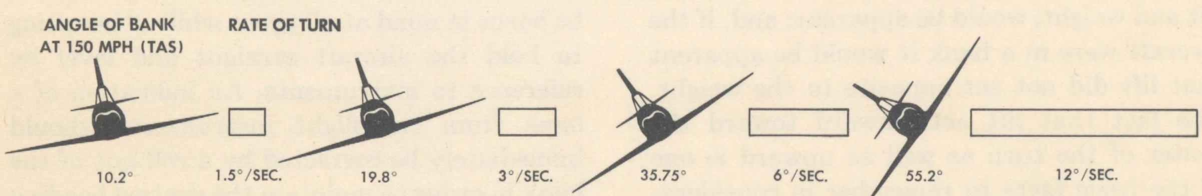


Figure 12. Rate of turn at 150 miles per hour.

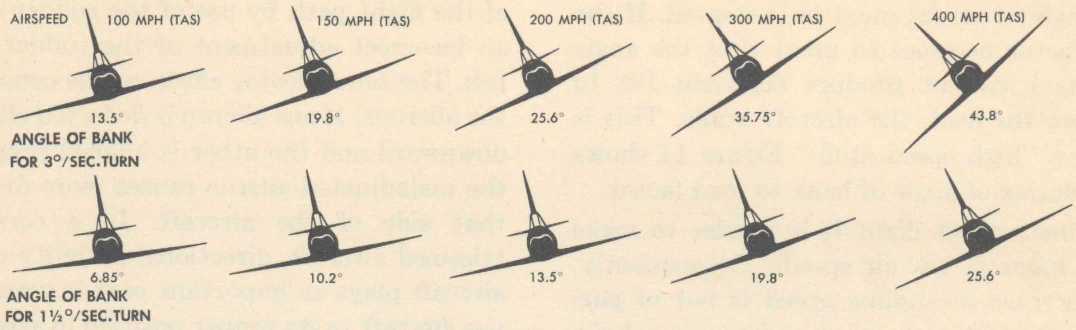


Figure 13. Angle of bank versus air speed.

the air speed is increased, the angle of attack must remain constant and the angle of bank increased. The increase in air speed results in an increase of the radius of the turn, and that centrifugal force is directly proportional to the radius of the turn. In a correctly executed turn, centrifugal force must be exactly equal and opposite to the horizontal component of lift. Therefore, in a constant-rate level turn, as the air speed is increased, the radius of the turn increases. This increase in the radius of turn causes an increase in the centrifugal force, which must be balanced by an increase in the horizontal component of lift. The horizontal component of lift can only be increased by increasing the angle of bank.

In order to maintain a given rate of turn, the angle of bank must be varied with the air speed. This becomes particularly important in high-speed aircraft when the indications of the turn needle are relied upon. For instance, at 400 miles per hour, an aircraft must be banked approximately 44° to execute a standard rate turn (3° per second) on the turn indicator. At this angle of bank, only about 79 per cent of the lift of the aircraft comprises the vertical component of the lift; the result is a loss of altitude unless the angle of attack is increased sufficiently to compensate for the loss of vertical lift. Figure 13 shows the angles of bank for standard rate turns of 3° per second, and ½ standard rate turns at the rate of 1½° per second for different air speeds.

The Load Factor and Angle of Bank In Turns

The load factor is the ratio between the load acting upon the aircraft in level flight and other possible loads that may be exerted on the aircraft. It depends upon the weight of the aircraft and the maneuver to be executed. For a coordinated turn, the load factor is equal to the total lift of the airfoil divided by the weight of the aircraft. Since the weight of the aircraft must be supported by the vertical component of lift, an increase in the angle of bank results in an increase in the load factor. In level flight, the load factor is 1, and in a 60° bank, the load factor is 2. This means that the wings support a load equal to twice the weight of the aircraft and in order to do this,

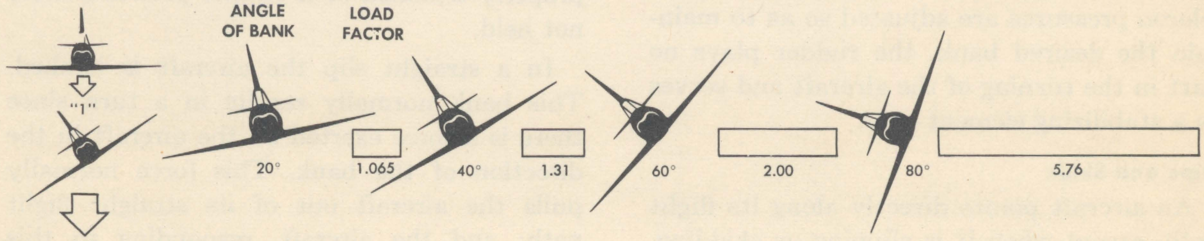


Figure 14. Load factor and angle of bank.

the angle of attack must be increased. If the load factor becomes so great that the angle of attack cannot produce sufficient lift to support the load, the aircraft stalls. This is called a "high speed stall." Figure 14 shows the relation of angle of bank to load factor.

In instrument flight it is unwise to make steep turns at low air speeds. Consequently, the increase in stalling speed is not of particular importance except under unusual circumstances. For instance, when ice forms on an aircraft, its stalling speed is increased. Since the stalling speed of the aircraft increases as the load factor increases, any further increased load factor because of a turn may result in a stall. Also, in extremely turbulent air the load factor on the wings may be increased by vertical gusts, and this increase may be sufficient to make an aircraft stall during a steep turn, whereas it would not have stalled in a moderately banked turn.

Aileron Drag

The rudder plays an important part in correctly executed turns. As the aircraft is rolled into a bank, the ailerons are deflected. This has the effect of increasing the lift on one wing and decreasing the lift on the other wing. The increased lift is on the outside wing, and increased lift means increased drag. This increased drag on the outside wing, known as "aileron drag," produces a yawing effect on the aircraft toward the outside of the turn, and if aileron is used exclusively to make the turn, this yawing results. Aileron drag is counteracted and minimized by using rudder pressure in a correctly executed turn. Once the bank is established in a turn and the aileron pressures are adjusted so as to maintain the desired bank, the rudder plays no part in the turning of the aircraft and serves as a stabilizing element only.

Slips and Skids

An aircraft points directly along its flight path, except when it is slipping or skidding. The aircraft may be yawed toward either side of the flight path by use of the rudder or by an incorrect adjustment of the rudder trim tab. The same yawing effect can be caused by the ailerons. If one aileron is deflected slightly downward and the other is aligned properly, the maladjusted aileron causes more drag on that side of the aircraft. In a correctly trimmed aircraft, directional stability of the aircraft plays an important part in returning the aircraft to its proper position in straight-

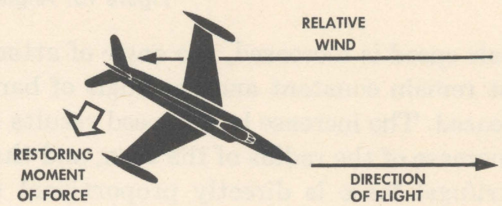


Figure 15.

and-level flight after a slip or skid. This directional stability is normally effected by the restoring moment created when the relative wind strikes the side of the rudder projected into the wind during a slip or skid. This is shown in Figure 15.

To maintain straight flight without slipping or skidding, the adjustments of the rudder trim tab must be varied for different power settings since changing torque will vary the air stream over the vertical tail surfaces and will vary the directional control. In many instances, a pilot will inadvertently hold rudder pressures or improperly set the rudder trim tabs and cause the aircraft to fly in a skid or slip. This, in turn, will give rise to many problems in directional control that would not be present if the aircraft where properly trimmed or if rudder pressures were not held.

In a straight slip the aircraft is banked. This bank normally results in a turn since there is a force exerted on the aircraft in the direction of the bank. This force normally pulls the aircraft out of its straight flight path; and the aircraft, responding to this force changes its direction of motion and be-

gins to turn. If these forces continue to act in this manner, the aircraft continues to turn. In a slip however, the aircraft is prevented from turning away from the original heading by the rudder action; thus, the bank of the aircraft results merely in its being pulled sideward. This is indicated on the flight instruments by the fact that the ball in the turn-and-bank indicator is displaced in the direction of the bank. If a pilot understands how an aircraft slips or skids, he will understand how to prevent slipping or skidding while flying by reference to the instruments.

Slipping Turns

Every pilot should understand the reasons for slipping of the aircraft during turns. A slip in a turn is similar to a slip in straight flight; the aircraft is not allowed to turn at a rate proper for the angle of bank. In a slipping turn, the rate of turn is not great enough for the angle of bank. The aircraft is not allowed to head directly along its turning flight path but is yawed to the outside of the path followed in the turn. The yaw may be the result of top rudder pressure, or in some aircraft, drag of the top aileron on entering the turn. As in straight slips, a slip in a turn is indicated by the displacement of the ball to the inside of the turn or in the direction of the bank. This indication is a result of the aircraft's being banked too much for the rate of turn, so that the resultant of gravity and centrifugal force acts downward. The first two views in Figure 16 shows an aircraft turning at the proper rate for the angle of bank, and another turning less than is proper for the angle of bank.

Skidding Turns

In a skidding turn the aircraft's rate of turn is too great for the amount it is banked. At a given rate of turn with an insufficient amount of bank, the centrifugal force and weight force produce a resultant that is not equal and opposite to the lift. This resultant acts toward the outside of the turn with respect to the direction of the force of lift. The skid carries the aircraft outward from the desired flight path and away from the direction of turn. The fact that the aircraft is skidding is indicated by the displacement of the ball in the turn-and-bank indicator to the outside of the turn. A skidding turn can be corrected either by reducing the rate of turn and holding the same angle of bank or, by increasing the angle of bank and holding the rate of turn constant. The third view in Figure 16, shows an aircraft in a skidding turn. Compare this view with the normal and slipping turns shown.

Coordinated Use of Rudder and Ailerons in Turns

Most aircraft may be banked by use of either ailerons or rudder alone. If the aircraft is banked by the ailerons only, it tends to slip, because the outside aileron causes more

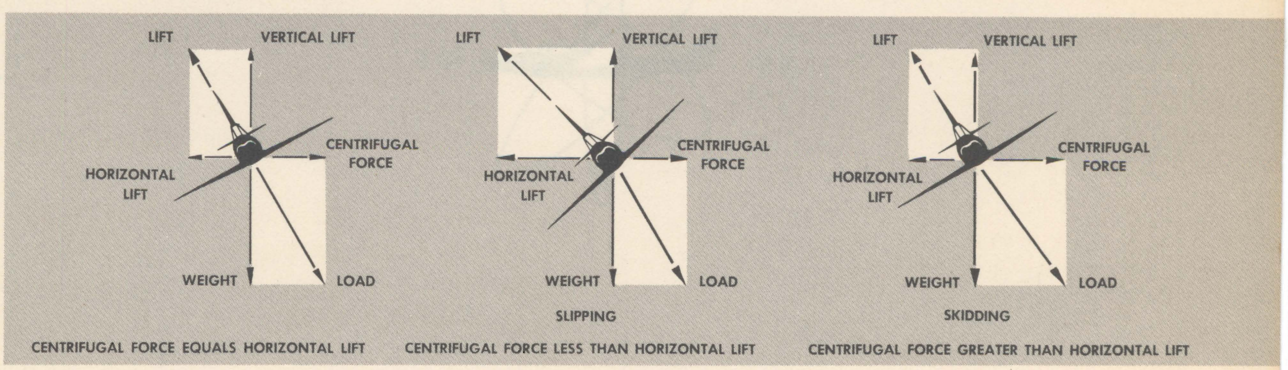


Figure 16. Normal slipping and skidding turns.

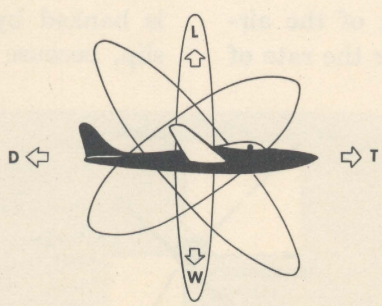
drag than the inside aileron. The amount of slipping depends upon the violence with which the controls are used, since the more the ailerons are moved out of a neutral position the greater is the yawing effect of the aileron drag. If the ailerons are used more slowly, the slipping is negligible.

An aircraft may be banked by the use of the rudder only. The aircraft is yawed toward the inside of the turn which increases the lift of the outside wing to a value greater than the lift of the inside wing. At best, the effect of the rudder is slow and if the rudder is used with any force, considerable skidding accompanies the increase in angle of bank. It is difficult to bank an aircraft flying at high speeds by the use of rudder alone because the yawing effects of the rudder do not materially increase the lift of the outside wing. In high-speed aircraft, the radius of the turn is so great that the increase in the speed of the outside wing over that of the inside wing is extremely small and has little effect upon the relative lift of both wings.

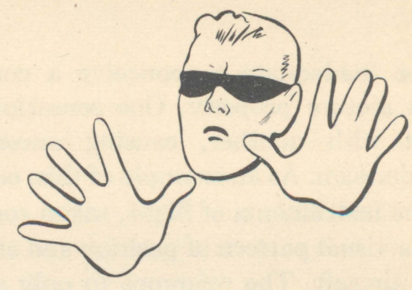
An aircraft is correctly banked only by the coordinated use of the rudder and the ailerons. The relative use of these two controls is determined by the characteristics of the particular aircraft and the air speed at which the maneuver is executed. The indications of the needle and ball instrument provide an accurate gage for determining the correct use of these controls. After the aircraft has been banked for a turn, the angle of bank should be held constant without skidding or slipping. This requires some adjustment of both ailerons and rudder pressure, depending on the characteristics of the aircraft and its speed. No general rules can be set for determining in advance the exact amount of rudder and aileron pressure to be used in turning any specified aircraft; the pressures must be learned from actual experience.

SUMMARY

The aerodynamics concerning the attitude of an aircraft are the same for instrument flight as for visual flight; however, an understanding of the relation of the aerodynamic factors, attitude, and control techniques, is essential if precision instrument flying is desired. This information is not intended for use by an aeronautical engineer, but, is expected to be used by a student or pilot as an aid in analyzing any possible deficiencies arising when attempting to control the attitude of the aircraft by reference to instruments.



CHAPTER THREE



Sensations of Instrument Flight

The ability to maintain equilibrium and orientation depends on sensations from the eyes, the motion sensing organs of the inner ear (vestibular organ), and the postural system (touch, pressure, and tension). If a pilot intends to do a left turn and ends up in a spin to the right, equilibrium and orientation are lost. This corresponds to a situation on the ground when one maintains his equilibrium and orientation and lies down, or loses equilibrium and orientation and falls down. When a person is standing, he maintains his equilibrium and orientation by use of his eyes, vestibular organ, and the postural system; if any one of these senses is lost, he must depend entirely upon the others. For instance, the eyes are the most important of the senses upon which we depend for equilibrium and orientation; therefore, if one is blindfolded, he finds standing a little more difficult and he finds that it is almost impossible to walk in a straight line. In instrument flying all outside reference that would normally aid the pilot in maintaining his equilibrium and orientation are lost.

Equilibrium and orientation in the air are altered in one important respect from the same functions on the ground in that the ground affords a stationary platform (fixed reference), whereas the aircraft introduces a movable platform (unreliable reference) which may go up, down, forward, or from side to side. The forces affecting the sensations are acceleration, centrifugal force, and gravity. These forces very seldom create erroneous impressions on the ground, but they do in flight, particularly in instrument flight. During flight, it is impossible for the postural senses to distinguish between the sensations caused by the pull of gravity and the sensation caused by centrifugal force. The vestibular organ of the inner ear cannot adequately detect small forces of acceleration and deceleration. A slow entry into a turn may not stimulate the vestibular organ at all, while a rapid recovery from the turn produces sufficient stimulation to cause the sensation of entry into a turn, opposite in direction to the initial turn. During sustained turns, the postural and vestibular senses cannot differentiate between turning and normal, straight-and-level flight.

The organs of sensation and the groups of sensations which these organs are continually sending to the brain form a basis for comprehension of a given situation. A single sensation

may be inadequate to conceive a complete mental picture properly. One sensation may conflict with another, causing uncertainty and indecision. As an example of this, consider that the instruments of flight, taken together, afford a visual pattern of position and attitude of the aircraft. The reference to only one instrument is insufficient. Also, the indication of one instrument may conflict with the indication of another, i. e., the swinging effect of the magnetic compass while making a turn from a heading of north to a heading of east as compared to the simultaneous indication of the turn-and-bank indicator. (See Figure 17.)

Under conditions of visual flight, the eyes are the instruments of the body. They register turn and bank and ascent and descent when the angles of variation from level flight are great enough, and to some degree they indicate the speed and direction of flight. They do this by considering the position of the aircraft relative to some fixed point of reference. Under the conditions of instrument flight, the fixed points of reference outside the aircraft are lost, but finer and more precise points of reference are available to the pilot on the instrument panel. The visual sense is the most dependable sensation to the pilot. The decision to rely upon the visual sense (believe the instruments), or to rely upon the vestibular senses (feel), demands judgment which is achieved only by training the brain to believe what the eyes see in the instruments.

The vestibular sense is extremely important to both man and animal in his natural environment, but it is held more responsible than any other sense for contributing to confusion in instrument flying. The vestibular organ is comprised of three semicircular canals connected to a sac. This sac is filled with a fluid which circulates throughout the entire vestibular system. Hairlike filaments of the vestibular nerve, stimulated by the alternation of pressure caused by motion (physical principle of inertia), register turns, tilts, slips, and skids. The vestibular sense is unreliable in instrument flight because the organ cannot distinguish between centrifugal force and gravity, which are often fused together in instrument flight; the resultant force cannot be interpreted without the aid of the visual sense. The vestibular organ senses only the changes of speed; it does not sense a constant velocity. This applies to linear and rotational acceleration and deceleration. Furthermore, the vestibular organ may not be stimulated at all if the

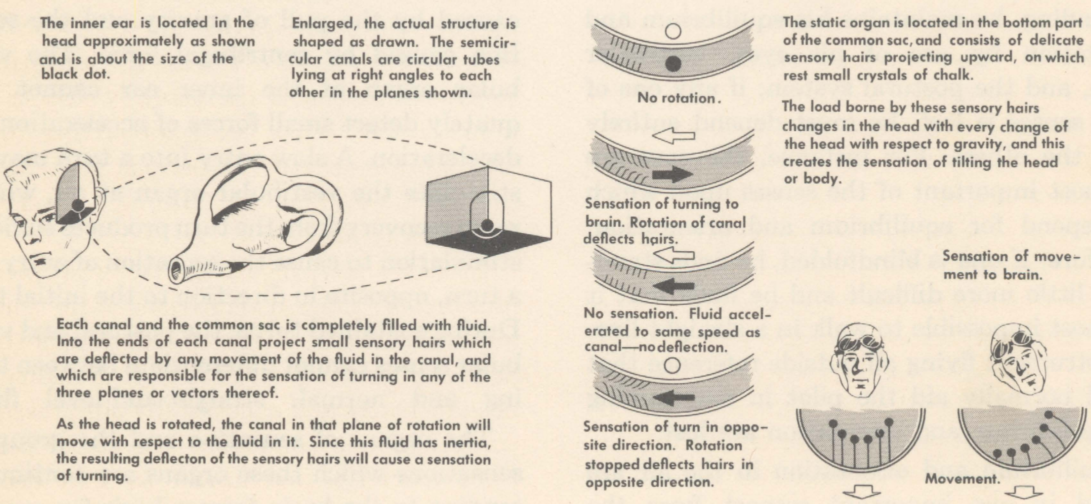


Figure 17

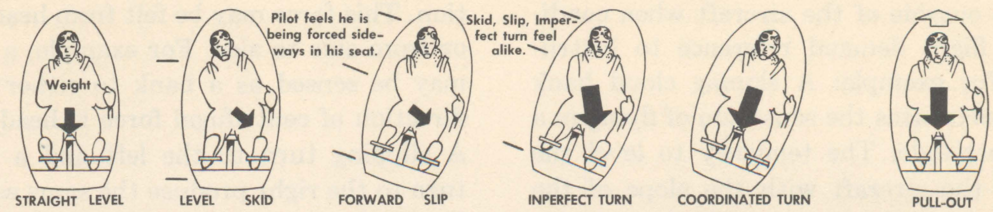


Figure 18. Sensations felt from centrifugal force.

acceleration is less than two degrees per second per second. The vestibular organ senses rotation in reverse when stimulated by decelerative force. The vestibular senses cause a normal person, when blindfolded, to walk or drive a vehicle in a spiral to the right or left. Blindfolded birds, when released in the air, set their wings for gliding until the ground is reached; cats cannot retain their remarkable ability to land on their feet when the vestibular organ has been removed; normal individuals experience reverse rotation when decelerated in a turn chair; until accomplished with practice, a normal person also experiences dizziness after whirling around several times. The sensation of dizziness is less impressive if the person uses his eyes as the dancer who picks out a reference point on either side of him and moves his head but once during each 180° turn. This trick enables the dancer to remain oriented. The whirling dervish and the ballet dancer experience reverse motion after rotation, but through training and constant practice they have learned to ignore or suppress the sensation; the tumbler gets dizzy but he does not show it because he is thoroughly familiar with its cause and has learned to compensate for it.

From the preceding comments on vestibular function and vestibular sensations, it is obvious that, while the vestibular organ may serve a useful purpose on the ground, it is entirely unreliable in instrument flying and, as a source of false illusion, it deserves serious consideration. If one is convinced of the reliability of visual senses through reference to the instruments, the proper evaluation may be placed upon the vestibular sensations. Otherwise, disaster is sure to follow.

The sensations which stimulate the postural sense are derived from stretching and contraction of muscles and tendons, touch and pressure, and the shifting of abdominal muscles. The postural sensations are more impressive in flight than on the ground, where they are understood clearly.

Centrifugal force and acceleration are felt in flight as rising or falling, and slipping or tilting from side to side, which are contrary to fact. Accurate postural interpretation is necessary if equilibrium and orientation are to be maintained. In instrument flight this must be accomplished by visual impressions from the instruments. The postural sense is unreliable in flight because the postural system cannot detect continued velocity without acceleration and deceleration. Some of the most common postural sensations are: the sensation of an elevator starting or stopping in movement when in constant motion; the sensation of starting and stopping in a pullman car with no sensation of continued motion if the track is smooth; the numbness of sensation from sitting in one position for protracted periods and the sensation of "walking on nothing" when one's leg "goes to sleep."

In instrument flight, the fact that sensory illusions are normal sensations of motion and are experienced by normal individuals should be remembered. Practically all illusions may be sufficiently and successfully suppressed by accepting with confidence the visual perceptions from the instrument so that decisive action may take place. Visual illusions may occur as a result of attempting to fly by visual

reference outside of the aircraft when conditions of flight demand reference to instruments. For example: A sloping cloud bank sometimes creates the sensation of flying in a banked attitude. The tendency to level the wings of the aircraft with the slope of the clouds is annoying if not confusing for the instruments contradict this impression of flight. The error is convincing when the ground is sighted again and the definite tilt of the plane is obvious. Reflected lights on the canopy may give the impression of a sharp bank or an attitude of inversion. Lights on the horizon may appear to be at a higher elevation than they actually are.

The illusions in instrument flight may be classified according to the force exerted on the body. Following a prolonged climb, to which the senses become accustomed, leveling-off may be accompanied by the sensation of diving, which might result in a stall. Likewise, following a prolonged gradual descent, leveling-off may, without appropriate adjustment of throttle, result in a dive. In an unexpected stall, the student often remembers the first few lessons of his instruction in which he was told that when the nose goes down, pull back on the stick; and when the nose goes up, push forward on the stick. At the break of the stall, the sensation of dropping, automatically invites excessive backward movement of the stick with the result that the controls are virtually "locked in position" for stalling. Rotational movements are limited in that the movement of the aircraft describes an arc of only a few degrees as in tipping or tilting from side to side. If the acceleration of the initial tilt exceeds two degrees per second per second the motion will be noticed. Recovery may take place at a slower rate, thus no sensation arises. The result is a persistent sensation of tilt to the right, whereas the aircraft has resumed level flight.

Centrifugal force tends to impel the person in the aircraft outward from a center of rotation. This force may be felt from head to seat or from side to side. For example, a pull-out may be sensed as a bank to either side for direction of centrifugal force is head to foot. A slipping turn to the left and a skidding turn to the right produce the same sensation. If a skid to the right is interpreted as a slip turn to the left the result might be a diving spiral to the left. The logical parallel of a slip turn to the left is a diving spiral to the right.

The combination of rotational acceleration and centrifugal force are brought to bear on the body in a turn of at least 25° of bank. Rotational acceleration and deceleration which accompany rolling into and out of the turn produce a sensation of reversal of rotation. The same sensation results if the aircraft's wings are leveled after being in a bank for a few minutes. Centrifugal force acts from head to seat and, if the turn is sustained, gives rise to the sensation of a pull-out of a dive. When the head, under the influence of centrifugal force in a pull-out or a sharp turn, is moved toward either shoulder, the sensation of a snap roll or spin is experienced. After watching the receding lights of a field at night pass the tail surfaces, a sensation of excessive climb is experienced when the pilot again turns his face forward. The sensation is difficult to suppress without instrumental guidance. (See Figure 18.)

Conviction of equilibrium and orientation are adjustments of the body necessary to the achievement of confidence in instrument flying. The sensations of instrument flight are normal perceptions experienced by normal individuals. Unfavorable sensations cannot be prevented, but they may be ignored or sufficiently suppressed by acquiring unreserved reliance upon visual sense of the instruments and the resultant judgment. The most critical single sense is vision; it is employed in the interpretation of the instruments of flight. Practice and experience aid in suppressing sensations and correcting interpretations.

CHAPTER FOUR

Magnetic Compass

Increasing emphasis on instrument flight has made the navigational procedures based on pilotage inadequate, and for the pilot, radio navigation and dead reckoning are the only present practical substitutes. Both are dependent upon accurate determination of direction.

Direction seeking devices are numerous, but most of them are either too complicated in their use or too subject to mechanical failure to be satisfactory to the pilot by themselves. The magnetic compass, however, is extremely simple in operation and does not require any power source. In order for the pilot to use the magnetic compass properly, he must understand its operation and the errors in indication, which, though sometimes large, can be accurately determined and allowed for.

Magnetic Fields

Since the magnetic compass works on the principle of magnetism it is necessary, during a study of it, to have at least a basic understanding of magnetism in general. A simple bar magnet has two centers of magnetism which are called poles. Lines of force flow out from each pole in all directions, eventually bending around and returning to the other pole. (See Figure 19.) The area through which these lines of force flow is called the field of the magnet. The poles usually are designated "north" and "south". If we place two bar magnets near each other, the north pole of one will attract the south pole of the other. Magnetic fields can be generated by an electric current passing through a wire. This practice is utilized in the design of electric motors, generators, solenoid switches and the like. In heating devices the magnetic field is not utilized but nevertheless is present.

THE EARTH AS A MAGNET

Observations of a freely mounted magnetic needle have proved that there is a magnetic field surrounding the earth. It acts very much as though there were a huge bar magnet running along the axis of the earth with its ends several hundred miles below the surface. The magnetic and geographic poles do not coincide. The North magnetic Pole is located in Baffinland at 73° N., 96° W., and the South magnetic Pole at 72° S., and 155° E.

The lines of force in the earth's magnetic field are parallel to the earth's surface at the

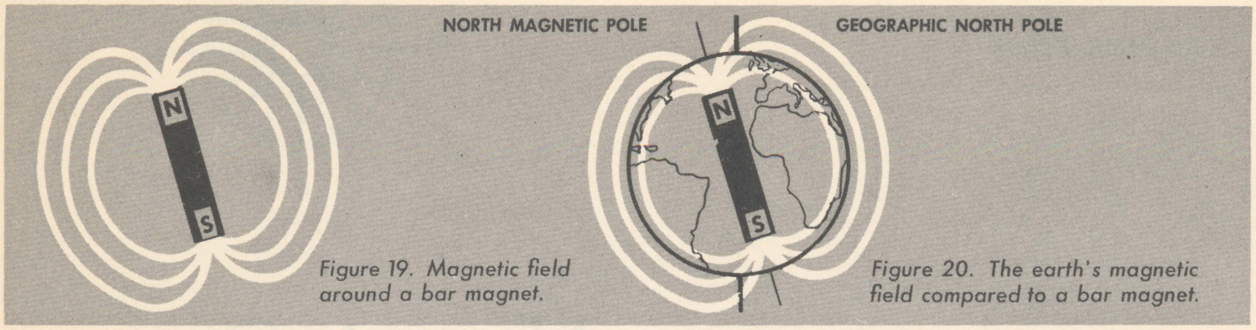


Figure 19. Magnetic field around a bar magnet.

Figure 20. The earth's magnetic field compared to a bar magnet.

magnetic equator but point increasingly downward when moving toward the magnetic poles themselves. Speaking technically, the lines of force have a vertical component which is zero at the equator but builds up to 100 per cent of the total force at the poles. If a magnetic needle is held along these lines of force, this vertical component causes a dip of the needle, a deflection downward. It is this deflection which causes some of the larger compass errors. (See Figure 20.)

CONSTRUCTION OF THE MAGNETIC COMPASS

The panel-type magnetic compass is simple in construction. It contains two steel magnetized needles mounted on a float around which is mounted the compass card. The needles are parallel, with their north-seeking ends pointed in the same direction. The compass card has letters for cardinal headings, and every 30° is represented by a number, the last zero of which is omitted. Between these numbers the card is graduated for each 5°. The float assembly which consists of the magnetized needles, compass card, and float is housed in a bowl filled with acid-free white kerosene. The purposes of this liquid are to dampen out excessive oscillations of the compass card and relieve by buoyancy part of the weight of the float from the bearing. The liquid also provides lubrication and prevents rust within the case of the instrument. From the bottom of the bowl is erected a pedestal upon which the float rests. Jewel bearings are used to mount the float assembly on top of the pedestal. At the rear of the compass bowl a diaphragm is installed to allow for any expansion or contraction of the liquid, thus preventing the formation of bubbles or possible bursting of the case. The glass face of the compass is an integral part of the bowl and has mounted behind it a lubber line, or reference line, by which compass indications are read. If the face is broken, the fluid is lost and the com-

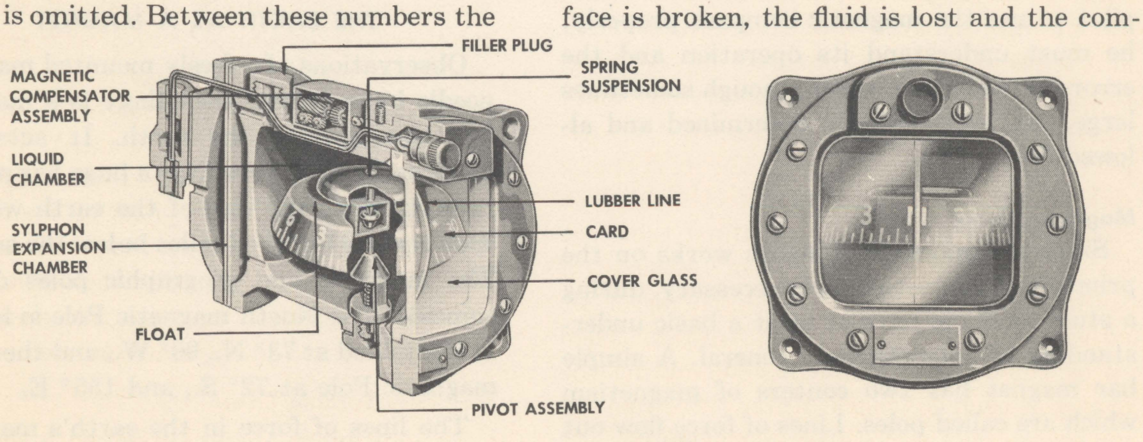


Figure 21. Panel-type magnetic compass.

pass becomes inoperative. On top of the compass is mounted a compensating device consisting of several small bar magnets which are adjustable by two set screws labeled N-S for north-south and E-W for east-west. (See Figure 21.)

COMPASS ERRORS

In navigation, course computations on aeronautical charts are based upon a relation of the course to the true geographic North Pole. During flight, the magnetic compass points to magnetic north which is not at the same location as the true North Pole. This angular difference that exists between true and magnetic north is known as variation. Lines of equal magnetic variation are called isogonic lines and are plotted on aeronautical charts with the amounts shown in degrees of variation east or west. A line connecting 0° points of variation is termed an agonic line. These lines are replotted periodically to take care of any change which may occur as a result of the shifting of the poles or any changes in local magnetic deposits. (See Figure 22.)

Electrical equipment mounted in the aircraft along with accessories made of iron or steel, such as guns and armor plate, may affect the reading of the magnetic compass. The difference between the indications of a compass in a particular aircraft and the indications of an unaffected compass at the same point on the earth's surface is called deviation. To reduce this deviation, compensating magnets on the compass are adjusted in the following manner: On a surveyed compass rose, point the aircraft toward magnetic north and compensate with the N-S screw until the compass reads correctly. Repeat this on a heading of east and adjust the error by use of the E-W screw. On headings of south and west take out half the error by adjusting the compensating screws. Then swing the compass through 360°, noting the errors at each 45° mark. Enter these remaining errors on the compass deviation card in the cockpit. (Deviation may change for each

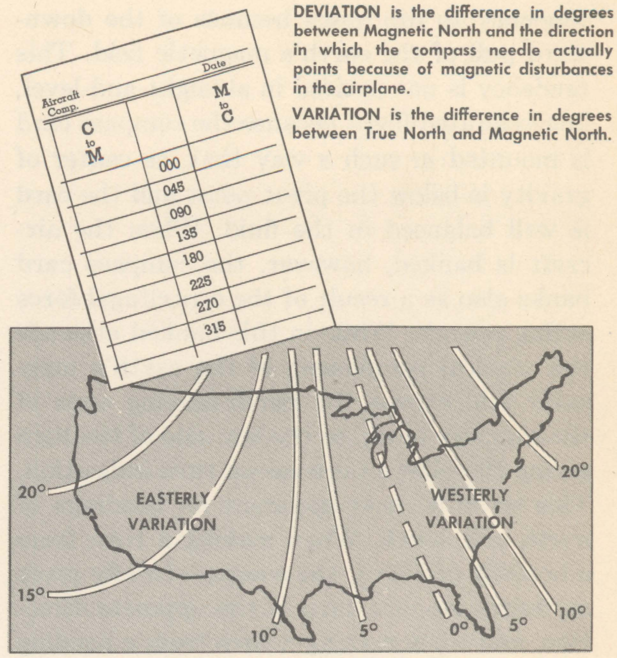


Figure 22.

piece of electrical equipment turned on and also the magnetism of the aircraft itself as a result of severe jolts.) Therefore, it is necessary to swing the compass periodically and prepare a new correction card.

Dip Error

The tendency of the magnetic compass to point down as well as north in certain latitudes is known as magnetic dip and is responsible for the northerly and southerly turning error as well as the acceleration and deceleration error on headings of east and west. At the magnetic equator, the vertical component of the earth's magnetic field is zero. At this latitude the magnetic compass is not disturbed by the vertical component. If we fly from the magnetic equator to the higher or lower latitudes, then the effect of the vertical component of the earth's magnetic field becomes pronounced. We will consider only the northern latitudes, because the errors are exactly reversed in the southern hemisphere.

Northerly Turning Error

In addition to aligning itself with the magnetic poles, the magnetic compass also has a

tendency to dip down because of the downward pull of the earth's magnetic field. This tendency is not noticed in straight-and-level, unaccelerated flight because the compass card is mounted in such a way that its center of gravity is below the pivot point and the card is well balanced in the fluid. When the aircraft is banked, however, the compass card banks also as a result of the centrifugal force acting upon it. While in this banked attitude the vertical component of the earth's magnetic field causes the north-seeking ends of the compass to dip to the low side of the turn giving the pilot an erroneous turn indication. This error is most apparent on headings of north and south. When making a turn from a heading of north, the compass briefly gives an indication of a turn in the opposite direction, and when making a turn from a heading of south it gives an indication of a turn in the proper direction but at a more rapid rate than is actually being made.

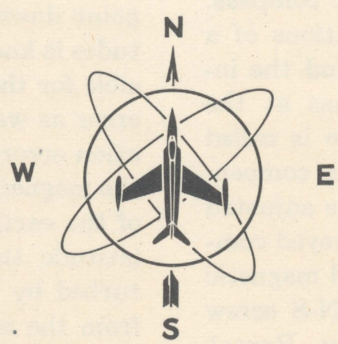
Acceleration Error

This error is also due to the action of the vertical component of the earth's magnetic field. Because of its pendulous-type mounting, the compass card is tilted during changes of speed. This momentary deflection of the card from the horizontal results in an error which is most apparent on headings of east and west. When accelerating on either of these headings the error is an indication of a turn to the north, and when decelerating the error is an indication of a turn to the south.

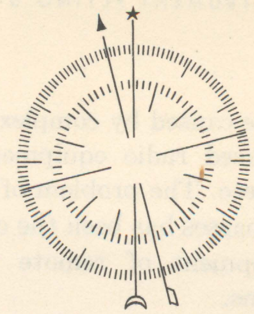
Oscillation Error

This error is caused by the erratic swinging of the compass card, which may be the result of rough air or rough-pilot technique. The fluid serves to reduce this oscillation.

The magnetic compass, if its errors and characteristics are thoroughly understood, offers the pilot the most convenient and reliable means of determining the direction upon which his aircraft is headed. While reading the compass to determine direction, the pilot should be certain that, the aircraft is held as steady as possible, to combat oscillation; the aircraft is not in a turn, however slight, and the air speed is being held constant.



CHAPTER FIVE



Remote Indicating Compasses

For many years the direct-reading card-type compass mounted on the instrument panel of aircraft has been the basis for aerial navigation. During the past decade, however, this type of compass has displayed many serious navigational faults. These faults are caused chiefly by the complexity in the construction of modern aircraft.

To overcome the disadvantages of the panel compass, new principles of operation have been developed. The practical development has been in the field of the remote-indicating compass systems. Two of these systems, the Magnesyn Remote Indicating Compass and the Gyro Flux Gate Compass are in wide-spread use in the Air Force and will be discussed in detail.

DISADVANTAGES OF THE DIRECT READING PANEL TYPE COMPASS

The panel-type compass is so mounted that when an aircraft is in straight-and-level, unaccelerated flight, the vertical component of the earth's magnetic field has no effect on the compass indications. When an aircraft is banked, however, on or near a heading of north or south, or when it is accelerated or decelerated on or near east or west headings, the compass indications are erroneous. Because of this dip error precision flying without the use of the directional gyro is difficult, especially in rough air. The panel compass is immersed in a fluid to dampen oscillations; however, this causes swirl error which may be noticeable. The comparatively small size of the compass bowl restricts the use of very efficient dampening vanes.

Before a magnetic compass will react properly, the earth's magnetic lines of flux must be strong enough to cause a bar magnet to line up with them. There is a definite variation in the strength of the earth's magnetic field. In the extreme latitudes (near the North and South Poles) the earth's magnetic field is very weak, and compasses may spin erratically or indicate an improper heading.

All panel-type compasses are constructed to compensate for disturbing magnetic influences within an aircraft. The compensating mechanism is satisfactory, when used with a correction card, as long as the deviation on any particular heading is constant. In modern aircraft, however, the deviation on any particular heading is seldom constant so the use of the correction card is limited. This variable

deviation can be caused by complex electrical systems, increased radio equipment, armament, loading, etc. The problem of deviation in aircraft compasses has been the chief cause for the development of remote indicating compass systems.

THE MAGNESYN REMOTE INDICATING MAGNETIC COMPASS SYSTEM

This compass system is designed to overcome the problem of deviation which is the main disadvantage of the panel-type compass. The three main components of the system are the transmitter, inverter, and the indicator.

The transmitter contains the directional compass element and should be placed in some remote portion of the aircraft such as the wing or the tail where there will be a minimum of magnetic interferences. The transmitter includes a float assembly, flux gate assembly, and a compensator assembly. (See Figure 23.)

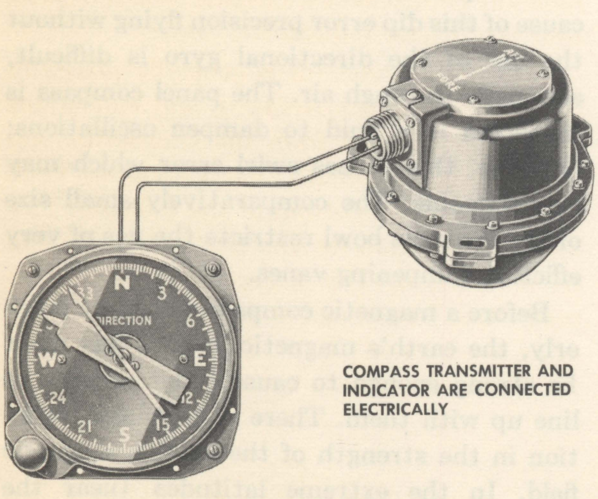
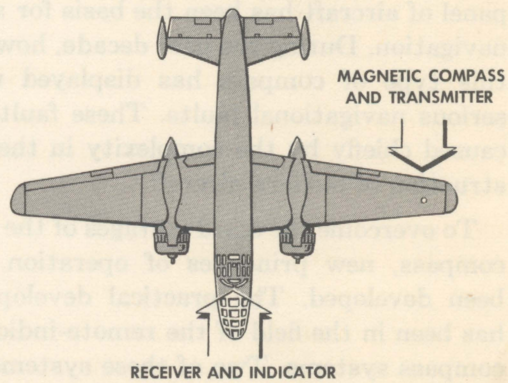


Figure 23. Magnesyn remote indicating compass.

The float assembly is immersed in a compass fluid within a bowl. The bowl is spherical in shape to make the float as free as possible of swirl error and friction. A diaphragm is provided for the expansion and contraction of the compass fluid. The float is equipped with four dampening vanes and is pivoted on a single post. It contains the directive magnet, or compass element, and the float is free to rotate at any angle up to 20° from the horizontal.

The flux gate assembly, or transmitter coil, is mounted directly below the compass element contained in the float. It contains no moving parts and operates on the principle of electromagnetic induction, which is the phenomenon whereby electrical voltage is induced in an electrical conductor when it is cut by magnetic lines of flux.

The compensator mechanism is much the same as on the panel-type compass. It consists of magnet assemblies on top of the transmitter, one for north-south compensation and one for east-west compensation. The procedure for compensating the compass is the same as on the panel-type magnetic compass.



The system operates with alternating current at either 400 cycles (26 volts) or 800 cycles (52 volts). If an aircraft's electrical system does not already include an inverter for other types of equipment, one must be supplied in order that the aircraft's supply of direct current may be converted to alternating current.

The indicator includes the housing, a receiving Magnesyn, and a dial and pointer. A

rotor in the indicator always assumes the same position in respect to the earth's magnetic field as does the compass element in the transmitter. This rotor is attached to the shaft of the needle on the dial. A course-setting pointer is operated by an adjusting knob. The indicator is not affected by the earth's magnetic field nor by any magnetic influences within the aircraft itself. As many as three indicators can be connected to the same transmitter.

The Magnesyn Compass System has a distinct advantage in that the deviation errors, if any, are constant, and the pilot need not worry about the effect upon it of electrical equipment, armament, cargo, etc. The pilot, however, must continue to fly "magnetic headings," know how to compensate for the effect of the vertical component of the earth's magnetic field during turns and accelerated flight, and expect poor indications in the extreme latitudes.

THE GYRO FLUX GATE COMPASS SYSTEM

This compass system, Figure 24, is designed to overcome the four main disadvantages of the direct-reading panel-type compass. The main parts of the system are: the transmitter, master indicator, amplifier, repeater indicator, inverter, and caging switch.

The transmitter contains the compass element, or flux gate. It is placed in a portion of the aircraft where it will be least affected by outside magnetic fields (usually within the wing).

The flux gate is the compass element. It is an electrical device that has certain voltages induced into it by the earth's magnetic field; the particular voltage depends upon the element's position in respect to that field.

The gyro is contained in the transmitter and is an electrical universally mounted gyro with a normal operating speed of 10,000 rpm. The flux gate is attached to the bottom of the gyro housing and consequently will always be horizontal to the earth's surface regardless of the aircraft's attitude or change of air speed. "Dip" error will never occur. The limits of operation of the gyro are 65° of pitch and bank.

An erection mechanism is incorporated on the gyro housing which will always keep the axis of rotation of the gyro in the vertical plane. It is accomplished by a small erection ball running in a circular track cut in the top of the housing, so that when the gyro is in its normal position, the ball will travel around the track at a constant speed (30 rpm). If the gyro tilts, the speed of the ball will not be constant thereby causing a precessional force which will erect the gyro. The caging mechanism is used for the same purpose as the caging mechanism on the artificial horizon, i. e., to erect the gyro quickly or to prevent damage when exceeding the limits of operation. It is remotely controlled by a caging switch located near the master indicator.

The master indicator is generally placed in the navigator's compartment, and indications which are received from the transmitter are read on a large azimuth dial. A variation knob is located at the bottom of the indicator face and the variation for any particular area can be set with it. This causes the indicator to read "true" headings at all times. Variation of as much as 56° E. or W. can be corrected for. With the variation dial set on 0°, normal

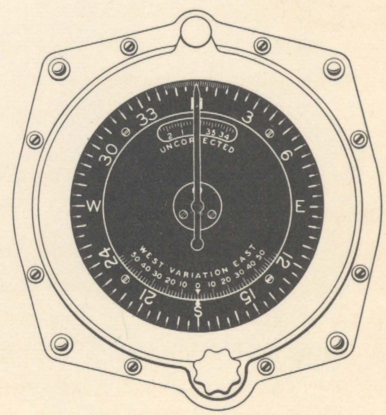


Figure 24. Gyro flux gate compass indicator.

"magnetic headings" may be read. Compensation for deviation is accomplished at the master indicator. It can be done at 24 points on the indicator face (every 15°) and thus eliminates the need for a compass correction card.

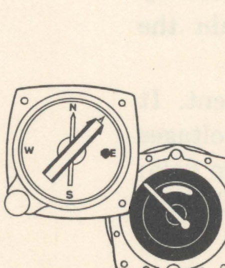
The amplifier is used to step up the signal received by the flux gate in order that it may be sent to the indicators. A gain-control is provided to increase the compass sensitivity in the extreme latitudes. There are five settings available and the "No. 3" is the position for normal use.

The repeater indicators are for the purpose of duplicating the readings of the master indicator at places other than the navigator's compartment. As many as six repeaters may be connected to one master indicator. Readings obtained on the repeaters incorporate the corrections for deviation and variation made at the master indicator. A course-setting pointer is provided on the repeater dial.

The inverter supplies the compass system with 115 volts of 400-cycle alternating current.

The fact that the gyro assembly is inaccessible to the operator makes necessary a remote caging switch to operate the caging mechanism. It can be any one of three types; push button, toggle switch, or manual crank. The first two operate an electric motor which, by means of a flexible drive shaft, turns the caging arm. The third type, which is found only on older installations, rotates the caging arm mechanically. With the push-button switch the gyro cannot be left in the caged position. On the toggleswitch type, the gyro can be left caged, and in that position, the compass indications are subject to "dip" error.

The two types of remote indicating compass systems in common use in the Air Force, the magnesyn remote indicating magnetic compass and the gyro flux gate compass system, have been designed to overcome the major disadvantage of the panel-type magnetic compass. The repeater indicators of both of these systems are identical. The magnesyn compass is extremely rugged in construction and requires no pilot adjustment or settings. The gyro flux gate compass involves certain operational procedures and demands the care and respect that should be given any instrument which involves the use of the gyroscope.



CHAPTER SIX

The Pitot-Static System

The air-speed indicator, altimeter and vertical-speed indicator, are part of the pitot-static system. These instruments are of prime importance to the safe operation of the aircraft through instrument conditions. It is for this reason that the attention of the instrument pilot should be directed to a consideration of the entire system's construction, operation, and use. A thorough knowledge of the system enables the pilot to evaluate the indications of the instruments and himself. This ability to evaluate correctly, plus confidence in himself enables the pilot to maintain the aircraft in a safe attitude, under very adverse circumstances, with comparative ease. The air-speed indicator and the vertical-speed indicator will be discussed in this chapter. The altimeter will be given complete coverage in a successive chapter.

THE PITOT-STATIC TUBE

The pitot-static tube is the beginning of the system and serves as the source of the pressures for operation of the air-speed indicator, vertical-speed indicator and the altimeter. It is mounted in a location on the aircraft where there is a minimum disturbance of the air due to the motion of the aircraft. This location wil vary on different types of aircraft. There are three major and essential parts to the pitot-static system; (1) the impact pressure chamber and lines, (2) the static pressure chamber and lines, and (3) the heating unit. A late development, in an effort to improve the pitot-static installation, has been to separate the pitot and static sources. The impact pressure is taken from the pitot tube, which is mounted on either the leading edge of the wing, the nose section, or the vertical stabilizer, and the static pressure is taken from a flush source. The static line is attached to a spot flush to the side of the fuselage, and carries the static pressure to the instrument. (See Figure 25.)

OPERATION OF THE PITOT-STATIC SYSTEM

The pitot chamber is open on the front of the tube. It is affected by the impact pressure of the air as the aircraft moves along. The static chamber, if it is contained in the pitot head, is vented through small holes on the top and bottom of the tube to the free undisturbed air. For most accurate operation the pitot-static tube should be parallel to the line of

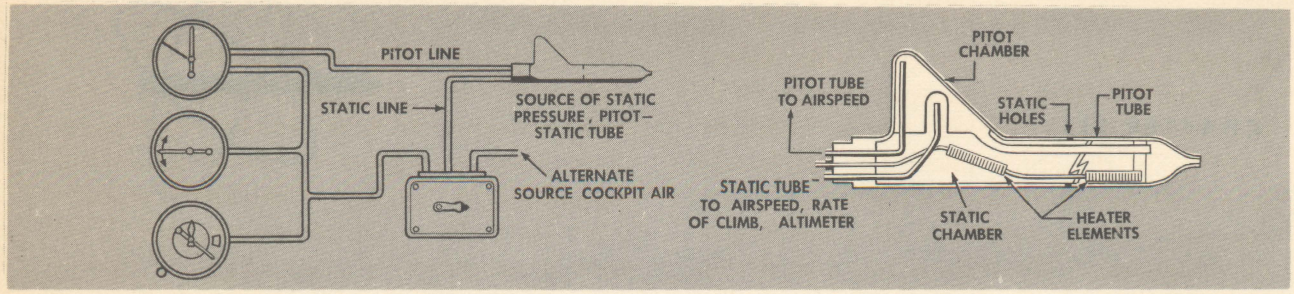


Figure 25. Alternate source, static pressure and tube.

the relative wind. This condition can best be approximated by mounting it parallel to the longitudinal axis of the aircraft.

An alternate source for static pressure is provided in most aircraft to be used in emergencies. This source usually taps its pressure from within the cockpit. Because of the venturi effect of the flow of air over openings in the aircraft, this alternate static pressure is usually lower than the pressure provided by the pitot-static tube. This is an important fact to be aware of because of the resultant effect upon the instruments when the alternate static source is used. The alternate source should be checked in flight when possible before going into instrument flight conditions. When the static source switch is placed in the alternate position the following differences usually occur; the altimeter reads higher than normal, the indicated air speed is greater and the vertical-speed indicator momentarily indicates a climb.

CONSTRUCTION AND OPERATION OF THE AIR-SPEED INDICATOR

The air-speed indicator has a cylindrical airtight case, which is connected to the static line from the pitot-static tube. Inside the case is a small diaphragm made of phosphor bronze or beryllium copper. The diaphragm is very sensitive to changes in pressure and is connected firmly at one side to the impact pressure line. The recording mechanism is a series of levers and gears which connect the free side of the diaphragm to the recording needle in the face of the instrument. (See Figure 26.)

The air-speed indicator is a differential pressure instrument. It measures the difference between the pressure in the impact pressure line and the pressure in the static pressure line. The two pressures are equal when the

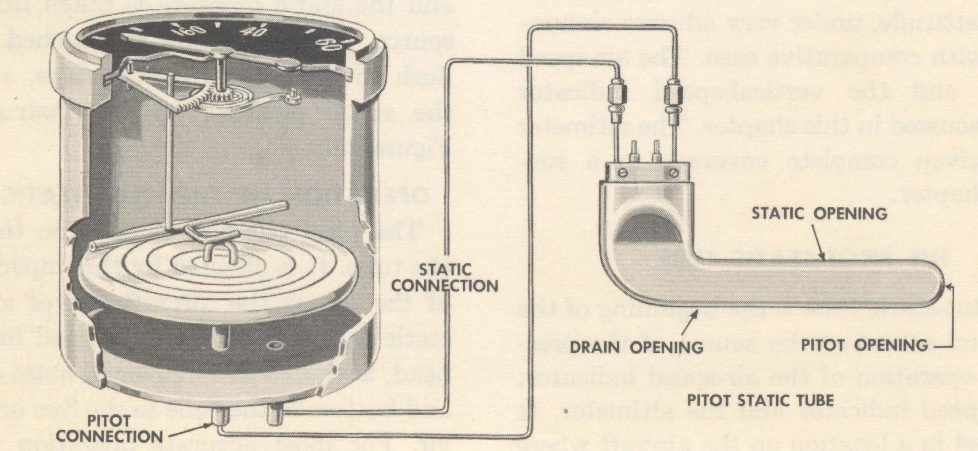


Figure 26. Air-speed indicator.

aircraft is stationary on the ground but movement through the air causes the pressure in the impact line to become greater than the pressure in the static lines. The diaphragm being connected directly to the impact pressure line will expand due to this increase in impact pressure. The expansion or contraction of the diaphragm is transmitted by a series of levers and gears to the face of the instrument to regulate the position of the needle. A dial is scaled so that the needle will indicate the pressure differential established by the pitot-static tube in miles per hour.

There are three kinds of air speeds, indicated, calibrated, and true. Indicated air speed is the air speed indicated by the needle of the air-speed indicator. Calibrated air speed is indicated air speed corrected for installation error. True air speed is calibrated air speed corrected for error due to air density (altitude and temperature).

The air density error which must be considered to compute true air speed is caused by the fact that the air-speed indicator cannot automatically compensate for densities varying from sea level density in the standard atmosphere. The installation error which is considered to compute calibrated air speed is caused by the fact that the differential pressure established by the pitot-static tube is slightly different from the theoretical differential pressure that it should establish. A flight error is sometimes caused by taking the pitot-static tube out of the line of relative wind by sudden changes of attitude. This error is negligible.

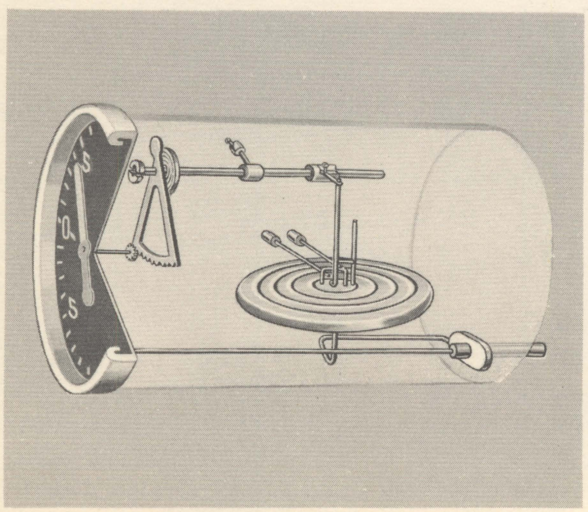


Figure 27. Vertical-speed indicator.

USE OF THE AIR-SPEED INDICATOR

There are many uses for the air-speed indicator, some of which are: to determine the rate at which the aircraft passes through the air, to determine the correct throttle setting for the most efficient flying speed, to determine the best angle for climbing and gliding, for keeping the diving speed within the safe limits of the aircraft's structure, and to indicate when flying speed has been attained when taking off. (It is most essential in determining the nose position in the pitching plane when flying on instruments.) The air-speed indicator has no lag. The apparent lag of this instrument following an attitude change is due to the inertia of the aircraft.

CONSTRUCTION AND OPERATION OF THE VERTICAL-SPEED INDICATOR

The vertical-speed indicator has a sealed case which is connected to the static pressure line through a calibrated leak. Inside the case is a diaphragm similar to that in the air-speed indicator. It is connected directly to the static pressure line. A system of levers and gears connects the diaphragm to the indicating needle on the face of the instrument. The vertical-speed indicator contains a mechanism whereby it is able to compensate automatically for changes in temperature and density of the air. (See Figure 27.)

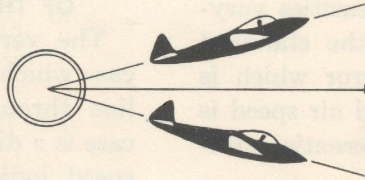
Although the vertical-speed indicator operates solely from static pressure, it, too, is a differential pressure instrument. The differential pressure is established between the instantaneous static pressure in the diaphragm and the trapped static pressure in the case. When the aircraft starts a climb the pressure in the diaphragm decreases, the diaphragm then contracts causing the needle to indicate

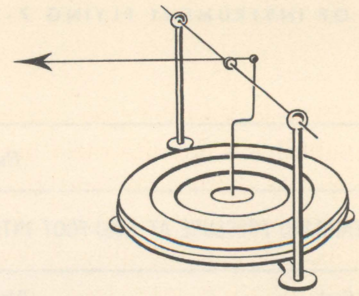
an ascent. The leak in the case is so calibrated that it maintains a definite ratio between the pressure in the diaphragm and the pressure in the case so long as a constant rate of climb is maintained. When the aircraft levels off it takes the calibrated leak from six to nine seconds to equalize the pressure in the case with the pressure in the diaphragm. This causes a lag of from six to nine seconds in the indications of the instrument. When the aircraft is descending the pressure inside the diaphragm is increasing. Again the calibrated leak maintains a constant ratio between the pressure in the diaphragm and the pressure in the case.

USE OF THE VERTICAL-SPEED INDICATOR

The vertical-speed indicator indicates the rate at which the aircraft is climbing or descending (or indicates level flight). These indications are not reliable in extremely rough air or when the attitude of the aircraft is constantly changing. This is due in part to the lag in the instrument. The instrument can be used to an advantage for indications of pitch attitude if the pilot has a thorough understanding of the effect of lag and considers this effect in interpreting the indications.

The pitot-static system demands one's studious consideration since the air-speed indicator, altimeter, and vertical-speed indicator are dependent on the system for their operation. The system furnishes static pressure to all three instruments and impact pressure to the air-speed indicator. The construction of all three instruments is similar in that each has an airtight case, an expandable diaphragm and a recording mechanism. A knowledge of the operation of each instrument will aid in interpreting the indications of each.





CHAPTER SEVEN

The Altimeter

Aeronautical records show numerous aircraft accidents which can be attributed solely to failure by the pilot to set his altimeter correctly. In the interest of safety, it is essential that every pilot become familiar with the proper use of this instrument. In flight, the altimeter is one of the most important instruments in the aircraft. In addition to affording the pilot a means of clearing obstructions, making low approaches and avoiding other traffic, its indications of altitude when combined with other factors provide a method of determining engine performance and computing true air speed.

THE ALTIMETER

The altimeter is a pressure-measuring instrument which may be compared to the aneroid barometer since it gives altitude indications by measuring pressure. If an aneroid barometer were carried aloft, the weight of the air still above it would be less and the reading on the barometer would also be less. When a simple aneroid barometer is calibrated in terms of altitude it is called an altimeter. All altimeters are calibrated to read altitude on the basis of the relation of pressure to height of a standard atmosphere as shown in the table on page 7-2.

Construction of The Altimeter

There are many kinds of altimeters in general use today; the Air Force alone has over a dozen different types. All, except the electronic-type altimeter, are constructed on the same basic principle of an aneroid barometer, namely, pressure responsive elements (aneroid wafers) expanding or contracting with the pressure changes of different flight levels. The heart of an altimeter is its aneroid mechanism which consists of one or more aneriod wafers. The expansion or contraction of the aneroid wafers with pressure changes actuates the linkage, and indicating hands show altitude. (Figure 28.) Around the aneriod mechanism of most altimeters is a device called the bi-metal yoke. It is, as the name implies, composed of two metals and performs the function of compensating for the effect that temperature has on the metals of the aneroid mechanism. The remaining small amounts of scale error resulting from temperature, are found on a scale-correction card, located in the cockpit near the altimeter.

Relation of Pressure to Elevation

STANDARD PRESSURE AT 1,000-FOOT INTERVALS		ELEVATIONS AT ONE INCH PRESSURE CHANGES ON STANDARD SCALE.	
Feet	Pressure	Feet	Pressure
16,000	16.21 in. Hg	19,696	13.92 in. Hg
15,000	16.88 in. Hg	18,026	14.92 in. Hg
14,000	17.57 in. Hg	16,445	15.92 in. Hg
13,000	18.29 in. Hg	14,942	16.92 in. Hg
12,000	19.03 in. Hg	13,509	17.92 in. Hg
11,000	19.79 in. Hg	12,140	18.92 in. Hg
10,000	20.58 in. Hg	10,829	19.92 in. Hg
9,000	21.38 in. Hg	9,571	20.92 in. Hg
8,000	22.22 in. Hg	8,358	21.92 in. Hg
7,000	23.09 in. Hg	7,190	22.92 in. Hg
6,000	23.98 in. Hg	6,063	23.92 in. Hg
5,000	24.89 in. Hg	4,973	24.92 in. Hg
4,000	25.84 in. Hg	3,918	25.92 in. Hg
3,000	26.81 in. Hg	2,896	26.92 in. Hg
2,000	27.82 in. Hg	1,903	27.92 in. Hg
1,000	28.86 in. Hg	939	28.92 in. Hg
Sea Level	29.92 in. Hg	Sea Level	29.92 in. Hg

Reading The Altimeter

The dial face of the altimeter (Figure 29.) is graduated with numerals from zero to nine inclusive. The large, or 100-foot pointer, makes one revolution for each 1,000-foot change of altitude; and each numeral reading is in hundreds of feet for this pointer. The second, or intermediate, pointer makes one revolution for each 10,000 feet and reads in thousands of feet with reference to the numerals on the dial. A small third pointer is provided which reads in tens of thousands of feet with reference to the dial.

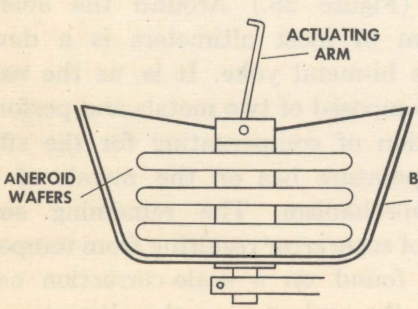


Figure 28.

Two triangular reference marks, each movable with respect to the graduated scale, are also on the dial face of the altimeter. One reference mark is located on the outside of the scale and reads in hundreds of feet. The second reference mark is located on the inside of the scale and reads in thousands of feet with respect to the numerals.

A pressure scale geared directly to the reference marks, but graduated in inches of mercury rather than in feet, has been incorporated in all but the earliest-type pressure altimeters. The pressure scale is graduated from 31.0 to

Figure 29.

28.1 inches of mercury. The scale is visible through a small window on the right side of the dial. Figure 29 shows an altimeter adjusted as follows: altitude 13,455 feet; reference marks −332 feet; pressure scale set to 30.28 inches of mercury. Before attempting to use this instrument, the pilot must thoroughly understand how to read it.

Types of Altitude

Defined, altitude is the vertical distance from some reference point. The types of altitude and the reference points that are important to the pilot are as follows:

True altitude is the height above sea level.

Absolute altitude is the height above terrain.

Pressure altitude is the height, or vertical distance, from the standard datum plane. This is a theoretical plane where air pressure (corrected by plus 15° C.) is equal to 29.92 inches of mercury.

Before determining his actual altitude, whether true, absolute, or pressure, the pilot should realize that all pressure altimeters are subject to small errors caused by the effect of different temperatures upon various metals of the instrument. A scale correction card showing the correction to be applied to the reading of the dial face should be posted near the altimeter. The application of this correction to the indicated altitude determines the "calibrated altitude," however, unless great accuracy is required, or if there is no scale correction card, the pilot may substitute indicated altitude for calibrated altitude, when correcting for free-air temperature in

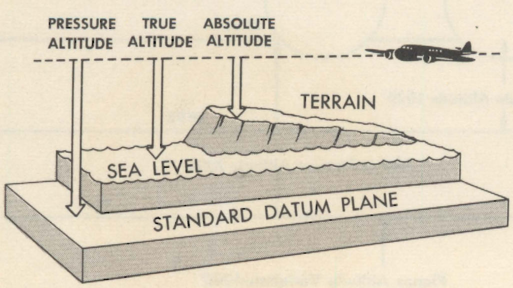


Figure 30. Type of altitude.

determining the actual altitude, by use of the E-6B computer (Fig. 4).

Setting Systems of The Altimeter

The various factors of sea level pressures and temperatures require frequent calculation to determine actual true altitude. If the pilots of two approaching aircraft had computed their true altitude on different pressure-temperature data of the areas through which they had flown, it would be very hazardous for them to attempt to pass. To achieve vertical clearance, all aircraft in a given area are given an arbitrary pressure level known as an altimeter setting. This setting must be used to correct the aircraft's altimeters. Altimeter setting may be generally defined as the pressure in inches of mercury of the reporting station reduced to sea level. Prior to

SCALE CORRECTIONS

Altimeter Reads	+24 ADD Room Temp.	−35 Low Temp.
0		
500		
1000	−10	+10
1500		
2000	−10	
2500		
5000	+10	
10000	+70	+170
15000	+140	
20000	+200	+270
25000	+200	

Date 17-July 1950

ALTIMETER No. 43-10668

Altimeter Reads	ADD Room Temp.	Low Temp.
30000	+150	+450
35000	+10	
40000	−310	+150
45000	−250	
50000		

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take-off the pilot should turn the knob on the altimeter until the pressure on the pressure scale is the correct value of the local field's altimeter setting, which is furnished by the tower. *The indicating hands should then read field elevation.* If there is an appreciable error (more than 75 feet) between indicated altitude and field elevation after the altimeter has been properly set, either the instrument or the given altimeter setting is in error. The weather officer computes the *existing* altimeter

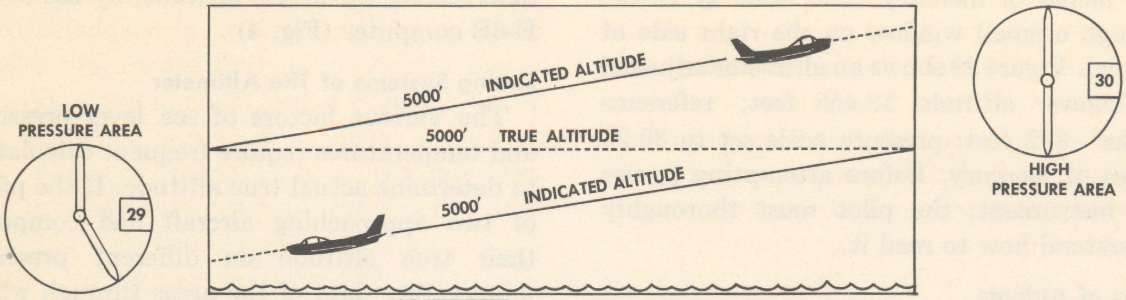


Figure 31. The effect of pressure on altitude.

setting by use of the barograph and scale, as is done frequently for sequence reports and for latest altimeter setting. If the altimeter is found to be in error an instrument maintenance man can easily correct it. Setting the pressure scale to altimeter setting, causes the altimeter to read indicated altitude. Flying indicated altitude ensures traffic separation, since in passing, the different altimeters are equally affected by whatever pressure and temperature conditions may exist. The pilots need not make allowance for nonstandard atmospheric conditions but must keep their altimeters adjusted to the latest altimeter setting. The danger of this system is that safe terrain clearance is not guaranteed; the indicated reading is generally the correct altitude only when the aircraft is about to land at the airport from which the setting was furnished. To determine adequate terrain clearance, the pilot must allow for possible errors in his indicated altitude; such as mechanical errors, temperature errors, change of pressure from the time the altimeter setting was computed to the time it is used, and the difference in pressure between the position of the aircraft and the station which reports the altimeter setting. During instrument flight and under conditions of poor visibility, it is very important that the pilot frequently reset his altimeter to the latest altimeter setting which can be obtained from a range station or control tower. Figure 31 illustrates this particular need when flying from a high-pressure area into an area of lower pressure.

Pressure Altitude Variation System

If the altimeter setting is not within the limits of the barometric scale on the pressure scale, or if the scale cannot be read, or is missing as in old-type altimeters, the pilot should use the pressure altitude variation system, which is identical with the altimeter setting system except that reference marks are set in feet to the same pressure equivalent

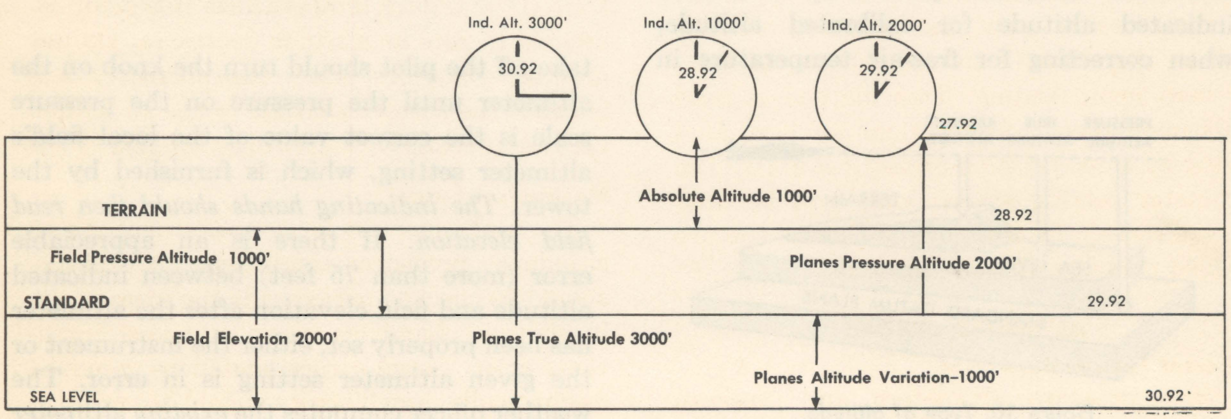


Figure 32. Pressure levels.

as would be expressed in inches of mercury on the pressure scale. Pressure altitude variation is the difference in feet between the 29.92 inches of mercury pressure level and sea level; an approximate calculation of pressure altitude variation can be made by remembering that one inch of mercury equals about one thousand feet. For example, if the altimeter setting is 30.38, the pressure altitude variation can be roughly computed as the difference between 30.38 and 29.92 or −460 feet. It is expressed minus in this case since the 30.38 pressure level is below 29.92. Tower operators will probably be familiar with the altimeter setting method only, and the pilot will have to make his own conversion.

standard pressure altitude relationship, the existence of nonstandard atmospheric conditions introduce inherent errors. For example, as shown in Figure 33, on a warm day the air having expanded is lighter in weight per unit volume than on a standard or colder day; so it is necessary to climb an additional 550 feet to reach the pressure level that will indicate 10,000 feet on a standard day. Much more dangerous to the pilot is the cold day. When he reaches a pressure level that indicates 10,000 feet, he is actually flying several hundred feet lower. The E-6B computer can be used to correct the indicated altitude for the temperature aloft; the resulting correction will be absolutely accurate only when the

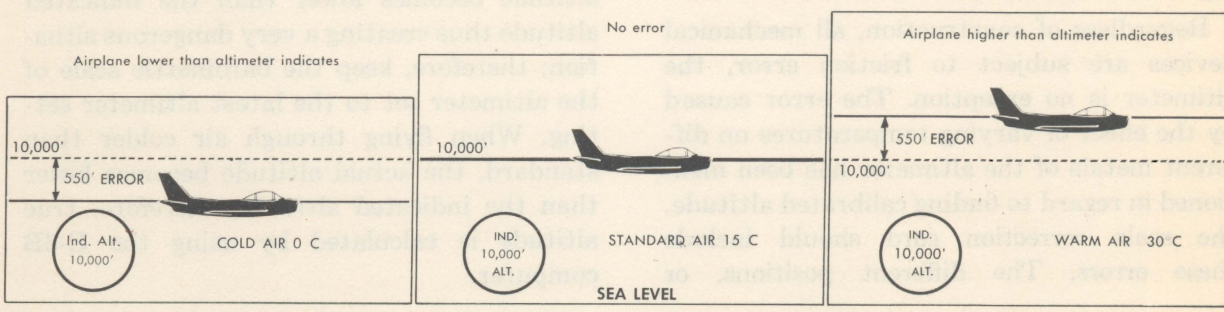


Figure 33. Inherent altimeter error due to temperature changes.

If the reference marks are correctly set the pilot will read field elevation upon landing. (See Figure 32.)

Field Pressure Method

When the field barometric pressure is set in the pressure scale, the indicated altitude will be the absolute altitude above the field, or zero upon landing. This method is used only upon specific instructions for local area flying by some training or tactical units. The altimeter setting system only will be used unless specific instructions authorize the use of field pressure altitude systems.

ALTIMETER ERRORS

Inherent Temperature Error

Since pressure altimeters are pressure gages calibrated in feet to a predetermined standard lapse rate exists; however, it is always more accurate than to assume the indicated reading to be the actual altitude. At 2,000 feet, the temperature error is 70 feet when the mean temperature varies 10° C. from the standard temperature; this error decreases to zero as altitude decreases. Do not assume, therefore, that the altimeter will indicate the correct altitude in the air simply because it reads correctly upon landing.

Mechanical Errors

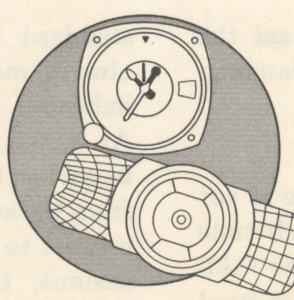
The scale may not be correctly oriented to standard pressure conditions. Altimeters should be checked periodically for scale errors in altitude chambers where standard conditions exist. Large errors should be removed mechanically; small errors should be recorded on the scale correction card.

The altimeter may tend to lag, particularly when large changes of altitude are made. These errors, which are called "hysteresis" or "after effect," will vary with the climb and descent. When an altimeter is taken aloft, to 19,000 feet for example, the indicated reading will be slightly low, gradually increasing as time passes. This increase, called "drift," is due to the elastic properties which were loaded in a state of equilibrium by the heavier pressures of ground level and require time to reach a state of equilibrium under the lighter pressures at 19,000 feet. Likewise, having remained at altitude for several hours, the instrument reads slightly high upon descending and gradually decreases, called "recovering," over a period of time.

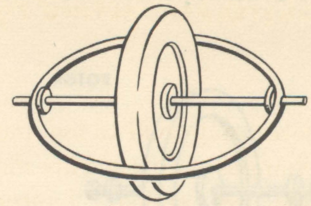
Regardless of construction, all mechanical devices are subject to friction error, the altimeter is no exception. The error caused by the effect of varying temperatures on different metals of the altimeter has been mentioned in regard to finding calibrated altitude. the scale correction card should include these errors. The different positions, or attitudes, that the altimeter assumes in flight may be a possible cause for error; however, the use of counter-weights in construction has largely eliminated incorrect readings due to the position of the instrument or any of its parts. Improper installation or damage to the pitot-static tube will, of course, result in wrong indications of altitude.

Pressure Errors

During instrument flight along airways, flight altitude is maintained by flying indicated altitude; however, the indicated altitude must be corrected for instrument and temperature errors in determining terrain clearance. When flying from an area of high pressure to an area of low pressure, the actual altitude becomes lower than the indicated altitude thus creating a very dangerous situation; therefore, keep the barometric scale of the altimeter set to the latest altimeter setting. When flying through air colder than standard, the actual altitude becomes lower than the indicated altitude; therefore, true altitude is calculated by using the E-6B computer.



CHAPTER EIGHT



Principles of Gyroscopes

If it were not for the utilization of the gyroscopic properties of a spinning wheel, precision-instrument flying, precise navigation and pinpoint bombing would be impossible. Instrument flying can be said to have been "born" when Elmer Sperry introduced his turn-and-bank indicator almost three decades ago. To realize the importance of the foregoing statement, consider some of the instruments which rely on a spinning wheel for their operation. The turn-and-bank indicator, directional gyro, artificial horizon, automatic pilot, B-3 drift meter, flux gate compass (gyro stabilized), and Norden bombsight all rely on the characteristic properties of a gyroscope. Gyros can be of any size, depending upon the use to which they will be put. The Sperry Company made one installation of three 164-ton gyros for the Italian steamship Conte de Savoia to stabilize the rolling of the ship in the ocean waves. The gyro wheels in flight instruments weigh about three quarters of a pound.

Any spinning object exhibits gyroscopic properties; however, a wheel designed and mounted to utilize these properties is called a gyroscope. Two important design characteristics of an instrument gyro are great weight or high density for size and rotation at high speeds with low friction bearings. The mountings of the gyro wheels are called "gimbals" which may be circular rings, rectangular frames or, in flight instruments, a part of the instrument case itself. (Figure 34.)

There are two general types of mountings; the type depends upon which property of the gyro is to be utilized. A freely or universally mounted gyroscope is free to rotate in any direction about its center of gravity. Such a wheel is said to have three planes of freedom. The wheel or rotor is free to rotate in any plane in relation to the base and is so balanced, that with the gyro wheel at rest, it will remain in any position in which it is placed. Restricted or semirigidly mounted gyros are those mounted so that one of the planes of

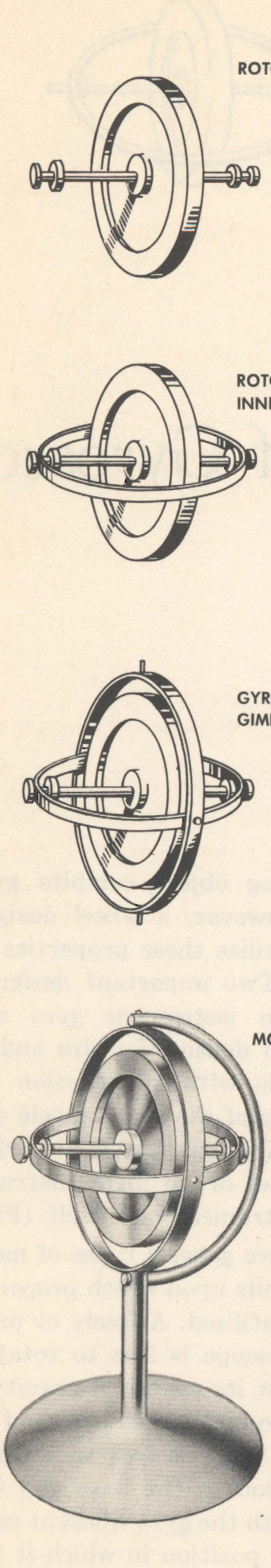


Figure 34.
Elements of a standard gyroscope.

freedom is held fixed in relation to the base.

PROPERTIES OF GYROSCOPIC ACTION

All practical applications of the gyro are based upon two fundamental properties of gyroscopic action, rigidity in space and precession.

Rigidity In Space

Newton's first law of motion states: "A body at rest will remain at rest, or if in motion in a straight line will continue in motion in a straight line unless acted upon by an outside force." An example of this law is the rotor in a gyro. It remains in any position it is placed regardless of how the base is moved. Since it is impossible to have bearings without some friction present, however, there will be some deflective effect upon the wheel. When the wheel is spun its rigidity is increased to such an extent that the deflective force of the bearings becomes negligible, and the wheel remains in its original plane of rotation regardless of the manner in which the base of the freely mounted gyro is moved about. (See Figure 35.)

The factors which determine how much rigidity a spinning wheel has are found in Newton's second law of motion which states: "The deflection of a moving body is proportional to the deflective force applied and is inversely proportional to its weight and speed." To obtain as much rigidity as possible in the rotor, it is given great weight for size, rotated at high speeds, and to keep the deflective force at a minimum, the rotor shaft is mounted in bearings which are as frictionless as possible. The two basic flight instruments which utilize the gyroscopic property of rigidity for their principle of operation are the artificial horizon and the directional gyro; consequently, their rotors must be freely or universally mounted. The most common cause for deflection in any gyroscope is friction in the bearings and pivots. The need for the two design characteristics (great weight for size, and rotation at high speeds) can be

understood when it is realized that a heavy body moving very fast is not deflected from its path as much as a very light, slow-moving object should they meet the same deflective force.

Precession

Precession is the resultant action or deflection of a spinning wheel when a deflective force is applied to its rim. When a deflective force is applied to the rim of a rotating wheel, the resulting force is 90° ahead in the direction of rotation and in the direction of the applied force. The rate at which the wheel precesses is inversely proportional to the speed of the rotor and proportional to the deflective force. The force with which a wheel precesses is the same as the deflective force applied (minus, of course, friction in the gimbal ring, pivots, and bearings). If too great a deflective force is applied, however, for the amount of rigidity in the wheel, the wheel precesses and topples over at the same time. A bicycle wheel may be used to make a very striking demonstration of rigidity in space and precession at the same time. If the wheel

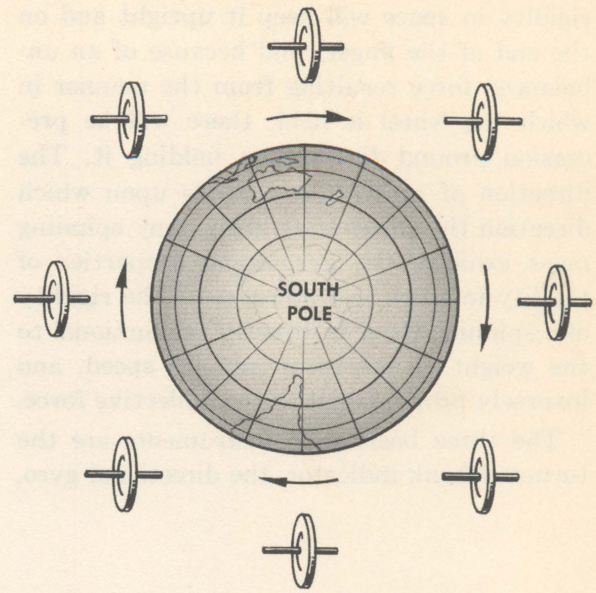


Figure 35.
Action of a freely mounted gyroscope.

is not turning it does not remain upright when one end of the axle is placed in the palm of the hand. If the wheel is spun, however, and one end of the axle is placed on the end of the finger with the wheel in the upright position,

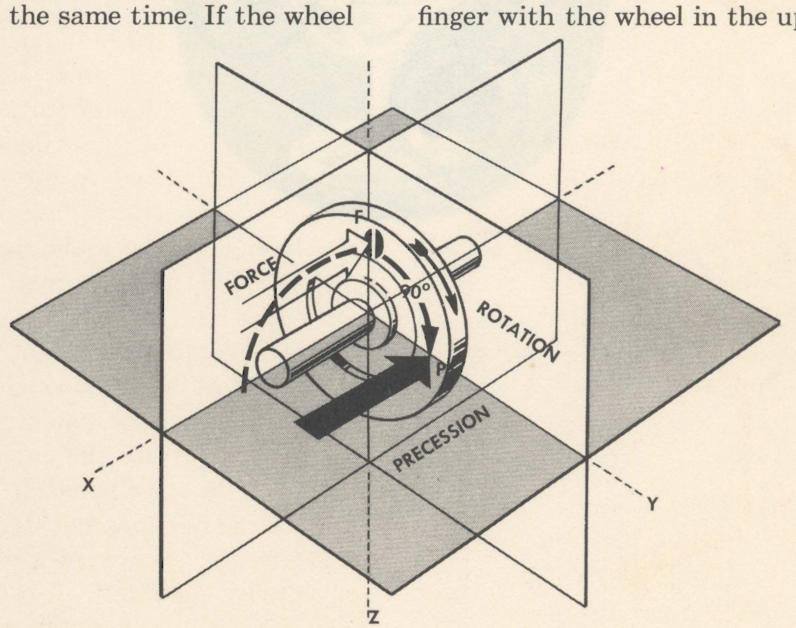
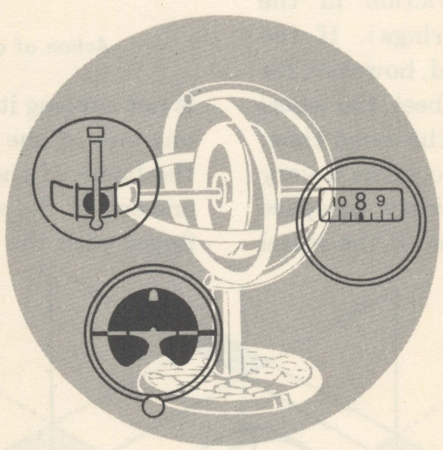
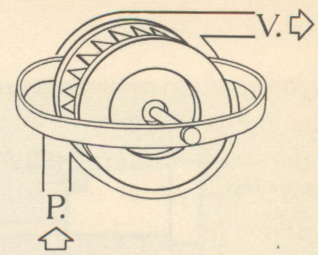


Figure 36. Precession of a gyroscope resulting from an applied deflective force.

rigidity in space will keep it upright and on the end of the finger; and because of an unbalanced force resulting from the manner in which the wheel is held, there will be precession around the person holding it. The direction of precession depends upon which direction the wheel is rotating. Any spinning mass exhibits the gyroscopic properties of rigidity in space and precession. The rigidity of a spinning rotor is directly proportional to the weight of the rotor and its speed, and inversely proportional to the deflective force.

The three basic gyro instruments are the turn-and-bank indicator, the directional gyro, and the artificial horizon. The turn-and-bank indicator utilizes the gyroscopic property of precession and is a semirigidly mounted instrument. The directional gyro is freely mounted and utilizes the gyroscopic property of rigidity in space to establish a reference plane and the gyroscopic property of precession to maintain the vertical plane of rotation of the gyro. The artificial horizon is freely mounted and utilizes the gyroscopic property of rigidity in space to establish a reference plane and the gyroscopic property of precession to maintain the vertical axis of the rotor perpendicular to the earth's surface.





CHAPTER NINE

Vacuum Systems

To keep the rotors of the gyroscopic instruments rotating continuously, a suitable means of motivation must be used. This calls for a system which must not only be reliable, but also simple. In present-day aircraft, this motivation is accomplished by a vacuum system or by electricity. Since the vacuum sytem is the one most commonly used, it will be discussed in this chapter.

THE PLAN OF THE VACUUM SYSTEM AND THE FUNCTION OF ITS COMPONENT PARTS

The vane-type pump is standard on all service-type aircraft with the exception of gliders and aircraft containing electrically driven instruments. It gives a maximum of 10 in. Hg vacuum at engine operating speeds. The selection of the size of the pump for volumetric output depends upon the number of instruments to be run. The pump is mounted on the accessory drive shaft of the engine. It consists of a circular case inside of which fits a round shaft, mounted eccentric to the case. In this shaft are mounted four vanes, which are free to slide in and out of the shaft as it is rotated. Slots are placed in the case at appropriate positions to act as valves. Oil from the engine lubrication system provides lubrication, an air seal and cooling.

The Air-Oil Separator

The vacuum system contains an air-oil separator, the purpose of which is to recover the oil used in the vacuum pump for lubrication, etc. The oil is exhausted from the pump along with the air. The separator consists of an air-oil inlet, a perforated baffle plate to stop the flow of oil within the air, and outlets for the separated oil and air. As the oil flows from the separator by gravity, maneuvers exceeding 90° of bank cause oil to flow out of the air vent.

Vacuum Relief Valve

Above engine speed of approximately 1,000 rpm, the pump draws the maximum 10 in. Hg vacuum. This is more than is needed to run the instruments, so a relief valve is provided. The relief valve is an adjustable, spring-loaded valve vented to the atmosphere. If 4 in. Hg is desired in the line leading to the instruments, the tension in the spring is set so that anv

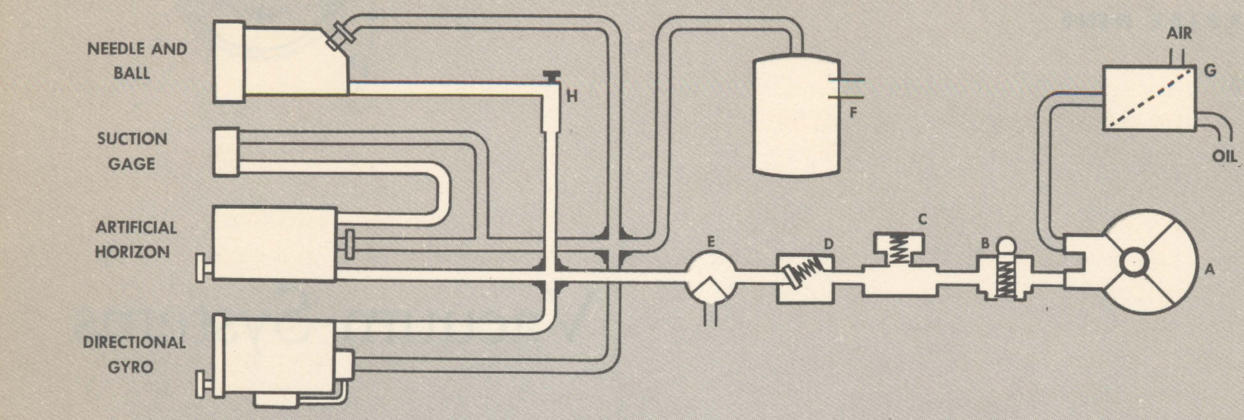


Figure 37. Suction system with master air filter.

vacuum in excess of this is drawn from the atmosphere through the valve opening.

Gate Check Valve

To prevent a reverse flow of air from the pump to the instruments in the event of an engine backfire, a check valve is used in the system. With a reverse flow of air there is danger of oil entering the instruments from the pump, so the check valve is incorporated to eliminate this possibility.

Pressure Relief Valve

When a backward flow of air from the pump closes the check valve and vacuum relief valve, a positive pressure results in this portion of the vacuum system. This pressure may become high enough to rupture the line connections, so between the check valve and suction pump a pressure relief valve is provided to vent the air to the atmosphere.

Turn-and-Bank Indicator Restrictor Valve

This valve is used to reduce the vacuum from 4 in. Hg in the main line to 1.9 in. Hg in the line leading to the turn-and-bank indicator. The construction of the valve is of two general types: (1) a needle valve which merely reduces the vacuum to approximately half the value in the main line, and (2) a spring-loaded regulating valve operating on the same principle as the vacuum relief valve. This type of valve maintains a constant vacuum on the turn-and-bank indicator regardless of the vacuum in the main line. When the spring-loaded restrictor valve is in the system, the vacuum on the turn-and-bank indicator will not be affected until the vacuum in the main line drops below the value for which this valve is set.

Alternate Source

Multiengine aircraft have pumps on more than one engine so in the event of failure of either a pump or an engine, vacuum will not be interrupted. Most single-engine aircraft do not have an alternate source, the reason being that a pump failure usually results from an engine failure. There is not much point in flying in-

struments on a dead engine. In most single-engine aircraft, however, a windmilling engine at gliding speeds provides adequate vacuum for instruments.

VACUUM GAGE AND VACUUM VALUES FOR INDIVIDUAL INSTRUMENTS

The artificial horizon and directional gyro operate satisfactorily with 3.5 to 5.0 in. Hg, the desirable vacuum is 4.0 in. Hg. The vacuum system should be adjusted so that the vacuum gage, which gives the values for these instruments, indicates between 3.75 and 4.25 in. Hg. The turn-and-bank indicator operates satisfactorily with 1.8 to 2.1 in. Hg, and desirable vacuum is 1.9 in. Hg. The vacuum should be adjusted to be between 1.8 and 2.05 in. Hg. To determine the amount of vacuum for the turn-and-bank indicator, it is necessary for a mechanic to attach a portable gage to the restrictor valve when the aircraft is on the ground. Older installations have lines leading from the case of the turn-and-bank indicator and the artificial horizon to a two-way valve connected to the gage. In this system the pilot can check the vacuum in either instrument by switching the valve.

FILTER SYSTEMS

The individual filter system, Figure 38, has its own individual air-inlet filter. It is used on all older model aircraft, and on some new types. The individual filter is a circular screen on the back of the instrument case which holds a very fine porous paper. All instruments now being manufactured still have an individual filter attached but are so made that they can be connected to a master filter when installed in an aircraft having one.

The master filter system (Figure 37) makes use of the large filter for all the instruments. Lines run from the intake port of the instruments through a common line to the filter. Using a master filter makes it necessary to clean only one filter, and it is mounted in a part of the aircraft where it is least exposed to air containing dirt.

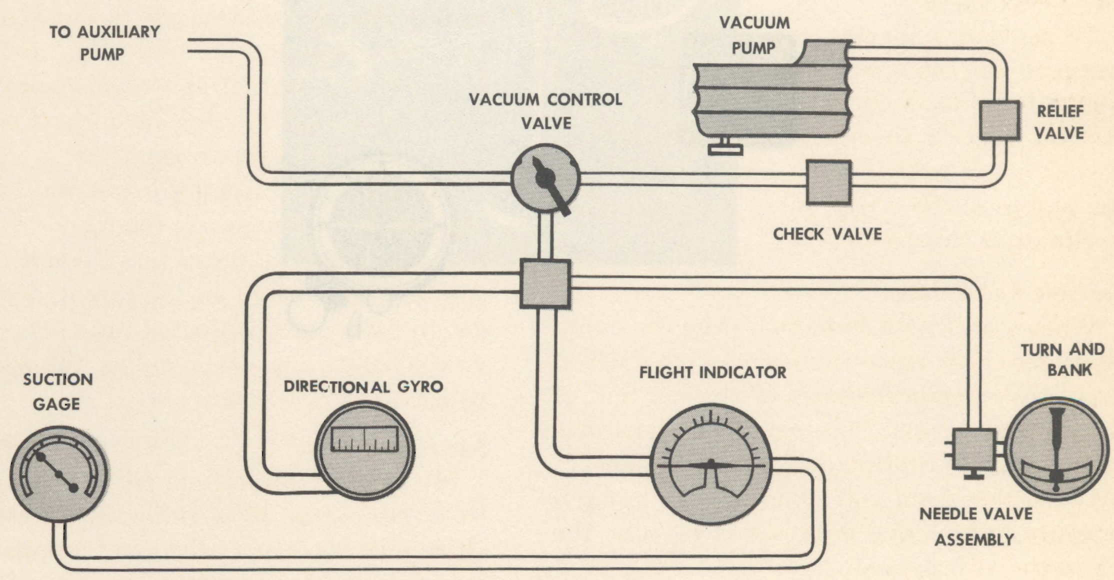


Figure 38. Individual filter system.

Effect of The Individual Filter System on Vacuum Gage Readings

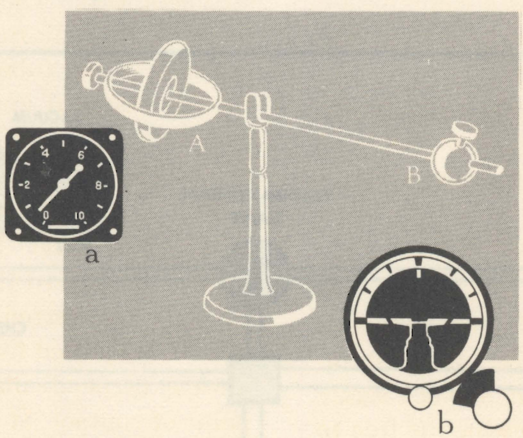
The vacuum gage shows the differential pressure between the case of the artificial horizon and the atmosphere. If the filter becomes clogged on any one, or all, of the instruments, it will not affect the reading of the vacuum gage. The vacuum relief valve takes care of any restricted flow through the filters. Hence, if the gyro instruments acted peculiarly, the vacuum gage would not give any hint as to the cause. It would continue to indicate the differential pressure created by the vacuum pump.

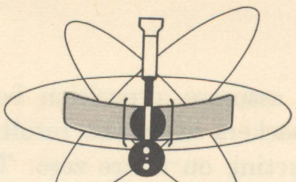
Effect of the Master Filter System on Vacuum Gage Readings

In the master filter system, the vacuum gage is connected to the line leading to the master filter and the artificial horizon case, thus giving the differential pressure between these two points. If the filter becomes clogged, and there is no flow or a restricted flow of air, and the pressure in the line and case become equal, then the vacuum gage shows a drop in vacuum.

Of the two filter systems the master filter system is by far the best. When using this system the pilot has a continuous check on the motivating force of the gyroscopic instruments. In the individual filter system the vacuum gage serves only to show that the pump is operating. It does not indicate the air-flow through the instrument cases as does the master filter system.

The two adjustments made in the vacuum system are on the vacuum relief valve and the turn-and-bank indicator restrictor valve.





CHAPTER TEN

Turn-and-Bank Indicator

The turn-and-bank indicator was one of the first modern-type instruments to be used for controlling an aircraft without visual reference to the ground or horizon. It is a combination of two instruments, a ball and a turn needle. The ball part of the instrument is actuated by natural physical forces, while the turn indicator depends upon the gyroscopic principle of precession for its indications. The gyro of the turn indicator may be driven by vacuum, or it may be electrically operated.

THE BALL

This part of the turn-and-bank indicator consists of a sealed curved glass tube containing water-white kerosene and a black agate or common steel ball bearing which is free to move inside the tube. The fluid provides a dampening action and ensures smooth and easy movement of the ball. The tube is curved so that when it is held in a horizontal position the ball has a natural tendency to seek the lowest point, which is the center. A small projection on the left end of the tube contains a bubble of air which compensates for expansion of the fluid during changes in temperature. Two strands of safety wire are wound around the glass tube approximately one-half inch apart. These strands of wire fasten the tube to a metal disc or plate in the front of the instrument case. They also serve as reference markers to indicate the correct position of the ball in the tube. The plate to which the tube is fastened and the reference wires are usually painted with a luminous paint. (See Figure 39.)

The natural forces acting on the ball in straight-and-level flight are: (1) gravity, which acts toward the center of the earth, and (2) the force exerted by the bottom of the tube. The force exerted by the bottom of the tube is always perpendicular to the tangent at the point of contact. It acts from the point where the ball makes contact with the tube through the center of the ball.

The natural forces acting on the ball in a coordinated turn are: (1) gravity, which pulls toward the center of the earth, (2) the force exerted by the bottom of the tube, which remains perpendicular to the tangent at the point of contact, and (3) centrifugal force which acts in the horizontal plane and outward from the center of the turn.

The ball assumes a position between the reference markers when the resultants of all the forces acting on it are zero. This occurs when the resultant of centrifugal force and gravity are directly opposite the force exerted by the bottom of the tube. When the forces acting on the ball become unbalanced the ball moves away from the center of the tube.

In a skid the rate of turn is too great for the angle of bank and causes unequal forces to act on the ball. The resultant of centrifugal force and gravity are not opposite the force exerted on the ball by the bottom of the tube, and the ball moves to the outside of the turn. To correct to coordinated flight necessitates increasing the bank or decreasing the rate of turn or a combination of both. (Figure 40.)

In a slip the rate of turn is too slow for the angle of bank and causes unequal forces to act on the ball. The resultant forces cause the ball to move toward the inside of the turn. To correct to coordinated flight requires decreasing the bank or increasing the rate of turn, or a combination of both.

The ball instrument is used to check the pilot's coordination. It is actually a "balance" indicator, because it indicates the relationship between the angle of bank and the rate of turn. It tells the pilot the "quality" of the turn, whether the aircraft has the correct angle of bank for its rate of turn.

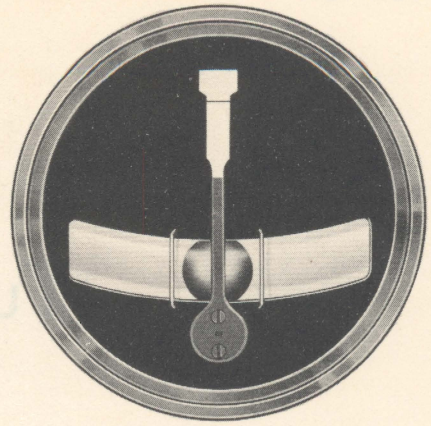


Figure 39. Turn-and-bank indicator.

THE TURN NEEDLE

The turn needle is actuated by a gyro which may be driven by vacuum or electricity. The gimbal ring encircles the gyro in a horizontal plane and is pivoted fore and aft in the instrument case. This mounting enables the gyro to rotate freely about the lateral axis and the longitudinal axis but restricts it about the vertical axis. The reversing mechanism causes the needle to point in the direction of turn. A round disc is attached to the gyro assembly. On the bottom of this disc a lever protrudes in a plane parallel to the longitudinal axis. Two parallel levers are attached to the shaft which

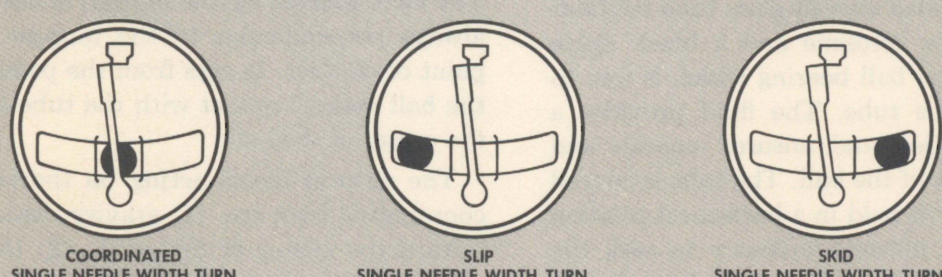


Figure 40. Indications of turn and bank indicator.

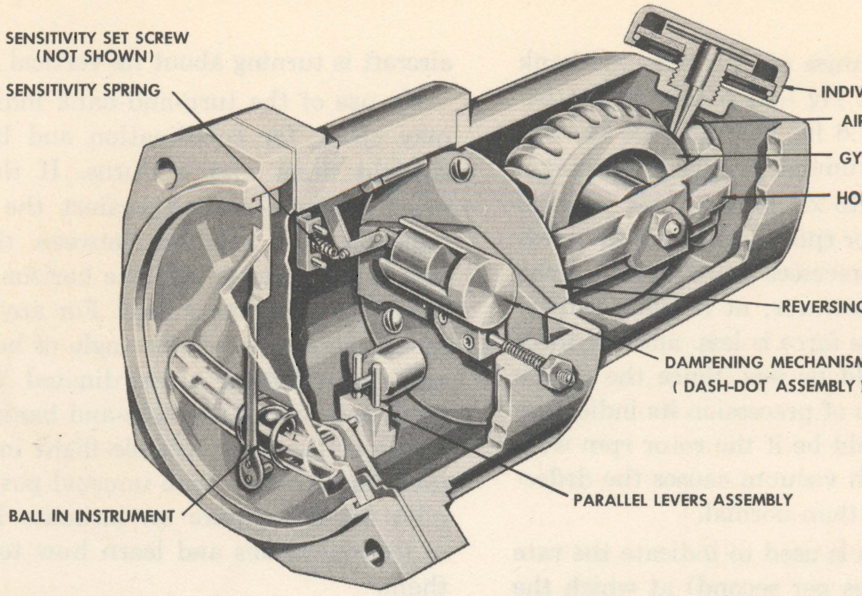


Figure 41. Cutaway view of Turn-and-Bank indicator.

turns the needle and extends upward, one on each side of the protruding lever from the bottom of the disc. This arrangement causes the needle to deflect in the opposite direction from the direction of precession of the gyro assembly. A sensitivity spring is attached at one end to the case and at the other end to the gyro assembly. This spring makes it possible to calibrate the instrument for a given rate of turn. It measures the force of precession. The spring also holds the gyro assembly perpendicular to the instrument case as long as no force is applied about the vertical axis. The tension on the spring may by adjusted by a set screw on the left-hand side of the case.

A dampening mechanism is provided to prevent excessive oscillation of the needle. This assembly is composed of a cylinder, a piston, and a rod which connects the piston to the gyro assembly. A small hole in the head of the cylinder, which may be adjusted in size by a set-screw on the right-hand side of the case, makes it possible to adjust the dampening effect of the needle.

A restrictor valve is used to control the suction on the turn needle. This valve is installed between the main suction line and the instrument. On the older systems the restrictor valve control is behind the instrument panel and is not accessible to the pilot. Some of the newer-model aircraft have a valve control on the instrument panel which enables the pilot to adjust the suction on the turn needle while in flight. On some models the suction gage may also be switched to the turn needle, thus making it possible for the pilot to know the actual suction on the instrument.

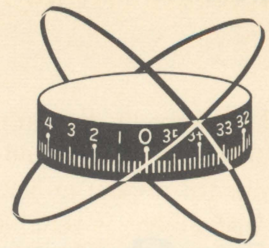
Operation of the Turn Needle

The turn needle utilizes the gyroscopic principle of precession for its indications. The gyro rotates up and away from the pilot about an axis parallel to the lateral axis of the aircraft. The gyro assembly always precesses about its longitudinal axis when a force or torque is applied about the vertical axis. Stops are provided to limit the precession of the rotor assembly to 45° in either direction away from the vertical. Owing to the direction of rotation of the rotor, the gyro assembly precesses in the opposite direction to which the aircraft is turning. This is desirable in order to prevent the axis of rotor rotation from becoming parallel to the vertical. The reversing mechanism causes the needle to indicate the direction in which the aircraft is turning so that the pilot may have a realistic picture of the attitude of the aircraft.

The desired vacuum on the turn-and-bank indicator is 1.9 in. Hg and should be set between the limits 1.8 in. Hg and 2.05 in. Hg; however, the instrument is reliable with suction of 1.8 in. Hg to 2.1 in. Hg. Low vacuum causes a lower rotor rpm. As a result the rotor is less rigid and precesses more from a given deflective force; however, at a given rate of turn, the deflective force is less, and the force of precession would be less. Since the needle measures the force of precession its indication is less than it would be if the rotor rpm were within limits. High vacuum causes the deflection to be greater than normal.

The turn needle is used to indicate the rate (number of degrees per second) at which the aircraft is turning about its vertical axis.

By use of the turn-and-bank indicator one may check for coordination and balance in straight flight and in turns. If this instrument is cross-checked against the air-speed indicator, the relation between the lateral axis of the aircraft and the horizon (angle of bank) may be determined. For any given air speed there is a definite angle of bank necessary to maintain a coordinated turn at a given rate. Since the turn-and-bank indicator is one of the most reliable flight instruments used for recovery from unusual positions, the pilot should acquire an intimate knowledge of its indications and learn how to interpret them.



CHAPTER ELEVEN

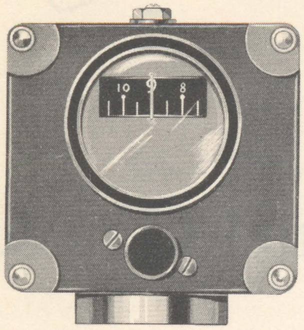
Directional Gyroscope

The directional gyro is fundamentally a mechanical instrument designated to facilitate the use of the magnetic compass. The most inexperienced pilot can realize the difficulties that would be encountered in instrument flying when depending solely upon the magnetic compass. Errors in the magnetic compass are numerous, making straight flight and turns to headings extremely hard to accomplish, particularly in turbulent air. The directional gyro, however, is in no way affected by the centrifugal force of turns, rough air, magnetic disturbances, or the orientation of the aircraft (within limits of the instrument). The calibrations on the card of the directional gyro replace objects on the horizon which are used as references for contact flight and actually make instrument flight more accurate than visual. (Figure 42.)

CONSTRUCTION AND OPERATION OF THE DIRECTIONAL GYRO

The operation of the instrument depends upon the principle of rigidity in space of a universally mounted gyroscope. The rotor of the instrument turns in the vertical plane. Fixed at right angles to the plane of the rotor (to the vertical gimbal) is a circular compass card. Since the rotor remains rigid in space, the points on the card hold the same position in space relative to the vertical plane. The case simply revolves about the card. The rotor, as has been stated, turns in the vertical plane but observations of the instrument under actual operation show that during turns the rotor may deviate from the vertical plane of rotation. The erecting mechanism, which is mentioned later in this chapter, quickly returns the rotor to its normal plane of rotation. (See Figure 43.)

The motivating force of the gyro is a stream of air (in the air-driven types) striking the rotor vanes or buckets, which are recesses in the rim. The speed of the rotor may vary from 10,000 to 18,000 rpm depending upon the design of the instrument. The pressure within the case is reduced below the existing atmospheric pressure by means of an engine-driven vacuum pump, which sucks air out from the rear of the case. This causes air under atmospheric pressure to pass through the inlet and internal filter at the base of the instrument case, through an air bearing into the hollow vertical gimbal ring and thence through the air nozzle and jets, striking the



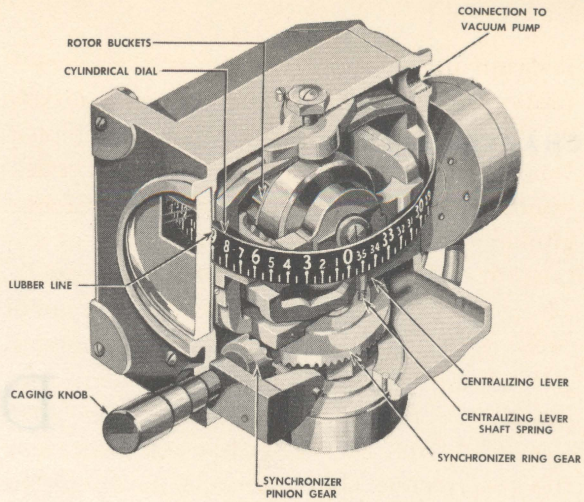


Figure 42. Cutaway of a Directional gyroscope.

rotor at a point just above the plane of the horizontal gimbal. For proper operation, the suction gage reading can be as low as 3.5 in. Hg and as high as 5.0 in. Hg, but the limits used for adjustment as specified by Technical Orders should be between 3.75 in. Hg and 4.25 in. Hg with 4.0 in. Hg being the desired reading.

During flight, sufficient errors occur to cause the rotor to precess away from the vertical plane. To compensate for these errors, and to provide better air flow distribution on the buckets, the air is divided by two parallel jets at the tip of the nozzle, each jet striking the buckets at points equidistant from the center of the buckets, while air from the other jet strikes the side of the buckets, causing the rotor to align itself by precession so that the plane of the rotor is parallel to the flow of air from the jets. This is an erecting action which takes place only when the rotor and vertical gimbal (or the flow of air from the jets) are in the same plane. (Fig. 43.)

In order to use the directional gyro properly, the pilot must be able to adjust the card. The caging mechanism provides this adjustment by rotating the vertical gimbal. This is possible by means of gears or by using a clutch. The Sperry type of directional gyro has a ring gear attached to the vertical gimbal and a smaller geared pinion attached to the caging knob. Pushing in on the caging knob meshes the gears, making it possible to turn the vertical gimbal and the card. The Jack and Heintz directional gyro utilizes a smooth metal ring on the vertical gimbal and a tapered rubber ring on the caging knob. When the caging knob is pushed in, the rubber ring makes contact with the smooth metal ring, and the resulting friction permits rotation of the gimbal and card. The operation, so far as the pilot is concerned, is the same.

When the vertical gimbal is grasped by pushing in on the caging knob, the gyro is no longer universal; therefore, turning the caging knob tends to cause the rotor to precess away from the vertical plane. To avoid this, the rotation of the horizontal gimbal ring is restricted by means of an arm attached to the vertical gimbal ring. When the instrument is caged, this caging arm touches the bottom of the horizontal gimbal, holding it and the rotor in the proper plane.

The pilot should be familiar with the limits of the directional gyro. Obviously, the instrument cannot operate in all attitudes of flight because of the nature of its construction and operation. If the plane of rotation of the rotor were able to become parallel to the base of the case, it would lose its ability to hold the card in a stationary position since its axis would be in line with the vertical gimbal and the card would tend to spin with the rotor. The stop or limiting factor in the

instrument is the caging arm. In the uncaged position, the caging arm rests on the bottom of the vertical gimbal ring and in that position restricts the movement of the vertical gimbal ring about the rotor or the horizontal gimbal. The caging arm is held against the bottom of the vertical gimbal ring by means of a small spring so that rough air cannot cause it to fly up and tumble the instrument.

The limits of operation of the instrument, for all practical purposes are, 55° of pitch and 55° of bank. It will be observed when using the instrument that on some headings the gyro does not spill or tumble even though 55° of bank or pitch have been exceeded. The directional gyro tumbles only when the vertical gimbal is rotated about the horizontal gimbal 55°. Flying the aircraft on a heading in which the plane of the rotor is aligned parallel to the wings of the aircraft, then banking in excess of 55° does not tumble the instrument since the vertical gimbal does not turn about the horizontal gimbal. If the rotor is aligned with the aircraft's longitudinal axis it will not tumble even though the aircraft's pitch attitude exceeds 55°.

When the horizontal gimbal touches the stop, the precessional force causes the card to spin rapidly. This may be corrected by caging and uncaging the instrument.

No gyroscope yet designed maintains the same plane of rotation. Because of several factors it precesses away from the original plane of rotation. This precession in the directional gyroscope causes the card to drift, or creep, away from the true reading. The chief cause of the creep or drift in the directional gyro is friction. The bearings used in gyroscopic instruments are as nearly perfect as can be obtained, and even they produce friction. When the gimbal rings move during flight, the friction of the bearings creates sufficient force on the rotor to cause it to precess. The amount of friction is increased if the bearings are worn, dirty, or not properly lubricated.

Another prominent source of error is the unbalanced condition of the gimbal rings. If the gyro unit is out of balance a force is applied to the rotor causing precession. Another cause of error which may sometimes become apparent is the effect of the rotation of the earth. This cause is usually unimportant in comparison with friction and unbalanced conditions of the gyro unit. The effect of the rotation of the earth on a universally mounted gyroscope is to cause it to precess, the amount of precession depending upon the position on the earth. At the equator there is no effect, and the direction of pre-

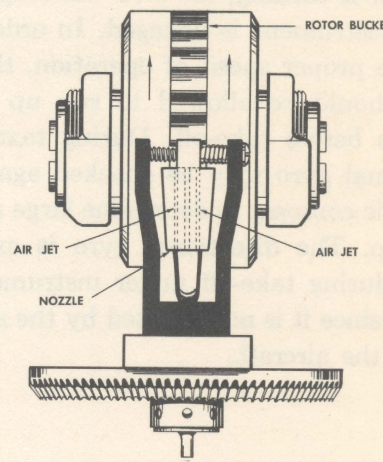


Figure 43.

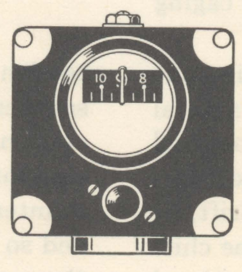
cession is opposite in the northern and southern hemispheres. The amount of precession depends upon the distance from the equator. The effect of the earth's rotation is counteracted by balancing the gimbal rings and so long as the plane flies somewhere near the same latitude creates no problem. If a flight entailing great changes of latitude were undertaken, however, the error would become apparent particularly if the equator were crossed. If the instrument were corrected for an error in the northern hemisphere, and flown in the southern hemisphere, the error and correction would act in the same direction causing a noticeable amount of creep.

When considering the errors in this instrument, it is well to remember that an apparent error in the directional gyro frequently results from improper use of the magnetic compass.

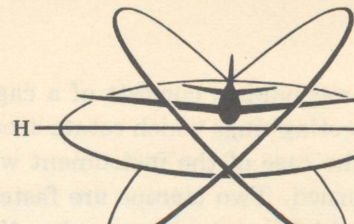
Before take-off, the instrument should be ground checked to determine whether it is operating properly. To do this first see that there is sufficient vacuum. The desired limits are 3.75 in. Hg to 4.25 in. Hg, with 4 in. Hg the desirable amount of vacuum. While the engine is warming up, check to see that the rotor is turning by first caging and then uncaging the instrument with a gentle twisting motion. If the rotor is turning, the card will stop as soon as the instrument is uncaged. In order to assure the proper speed of operation, the gyroscope should be allowed to run up for five minutes before take-off. During taxiing, the directional gyro may be checked against the magnetic compass to determine large amounts of creep. The directional gyro is extremely useful during take-off under instrument conditions since it is not affected by the acceleration of the aircraft.

During flight, the directional gyro is used to maintain straight flight and make turns to headings. Whether the pilot sets the card with the compass, or uses the heading of zero, he uses the magnetic compass as the reference. Great care should be used when reading the compass. Unless the pilot checks the compass deviation card, the gyro may appear to drift several degrees during a turn. The directional gyro should be checked at least every fifteen minutes against the magnetic compass. After setting the instrument, uncage it by pulling the caging knob straight out. If there is an error of more than 3° in a period of fifteen minutes write up the instrument on the Form 1A. When making an instrument write-up, include as much information as possible.

During maneuvers which exceed the limits of the instrument it should be caged. At all other times the instrument may be left uncaged. It is obvious that frequent acrobatic flight with the instrument uncaged shortens the life of the gyro unit. A great deal of force is applied to the bearings if the limits are exceeded and the gyro is "spilled."



CHAPTER TWELVE



Artificial Horizon

The artificial horizon with its miniature aircraft and horizon bar is the one instrument that portrays a pictorial idea of the actual attitude of the real aircraft. This is done by a horizon bar which is attached to a gyroscope in such a manner that the horizon bar remains parallel to the natural horizon, thus establishing a level reference plane inside the aircraft. An advantage of the artificial horizon is its instantaneous indication of even the smallest changes of attitude. It has no lead nor lag and is very reliable if properly maintained. This chapter covers the mechanical construction and theory of operation of the artificial horizon, the errors found in it, and its practical use in flight.

MECHANICAL CONSTRUCTION AND PRINCIPLES OF OPERATION

The basic mechanism in the artificial horizon is the gyro which is simply a rotor wheel mounted inside of an airtight housing. The rotor and housing are mounted so that the rotor spins in a horizontal plane about a vertical axis. The rotor is supported at each end by five ball bearings made of the very finest and hardest steel and their life, which is about two to four hundred hours, determines the life of the instrument.

The rotor housing is pivoted laterally inside of a gimbal which in turn is pivoted fore and aft to the cylindrical, airtight instrument case. The lower part of the rotor housing is a hollow chamber containing four holes or ports, each of which is half covered by a free-hanging pendulous vane that is diagonally mounted and connected by axles. The chamber containing the pendulous vanes is the erecting mechanism of the artificial horizon.

The horizon bar is linked to the gyro by a lever which is pivoted at one end to the horizontal gimbal ring and in the center to the gyro housing by a connecting pin; the horizon bar is attached near the end of the lever in order to be visible across the face of the instrument.

The limits of the instrument, which are determined by its construction, vary in degrees depending upon the series of the instrument used. Limits in the banking plane are usually from 100° to 110° and pitch limits vary from 60° to 70°.

The caging mechanism consists of a caging knob and projecting rings which rotate around the inside of the case of the instrument when the knob is turned. Two clamps are fastened to the rings which rotate in opposite directions and cause the clamps to come together and firmly hold the pin which projects from the gyro housing. (See Figure 45.)

The gyroscopic principle of rigidity in space is utilized to establish a reference plane within the aircraft, and the gyroscopic principle of precession is utilized to maintain the vertical position of the axis. When the rotor has tilted from the vertical axis, the automatic erecting device causes a force to be exerted against the rotor housing resulting in precession of the gyro back to the vertical axis. An air stream through the instrument spins the gyro and operates the automatic erecting device. The air enters the rear of the instrument through a screened filter and passes through an air bearing directly into the hollow passageway of the gimbal ring. From the gimbal ring the air flow enters the rotor housing through another air bearing. Two jets in the rotor housing direct the air stream against the rotor wheel buckets causing the rotor to spin in a counterclockwise direction at approximately 15,000 rpm. After turning the rotor, the air flows through holes into the lower part of the rotor housing and escapes through the four ports into the instrument case, completing the cycle. Desired vacuum is 4 in. Hg. The Technical Order calls for an allowable limit of 3.75 in. Hg to 4.25 in. Hg when adjusting the vacuum relief valve in the suction system for this instrument.

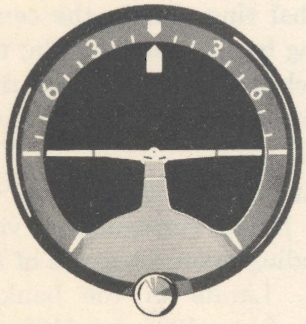


Figure 44. Artificial horizon.

The automatic erecting device consists of the lower part of the housing with its four openings or ports. Hanging freely and operating in pairs, each pendulous vane covers one-half of each of the ports. When the gyro is tilted off the vertical axis, the pendulous vanes still remain vertical which causes one port to be opened and the opposite one to be closed by the vanes. As a result, the escaping air through one port is cut off, while the other port allows a greater volume to escape by reason of its open condition. This unequal escape of air exerts a force (rocket effect) against the lower part of the rotor housing, causing the gyro to precess back to the vertical at a rate of 8° per minute.

ERRORS FOUND IN THE ARTIFICIAL HORIZON

Errors are almost always present in the artificial horizon. However, except in extreme cases their magnitude is seldom more than 3° or 4° of pitch or bank indication. Some of the common causes of error are: friction, unbalance, faulty construction, dirt, worn bearings, clogged filter system, and out-of-position pendulous vanes, swung from their vertical position by forces in turns, skidding flight, and acceleration or deceleration.

Haphazard error is caused by inadequate suction which in turn lowers the rpm of the rotor thereby causing the gyro to lose its rigidity. Reaction of the instrument in this case is unpredictable. The same result is effected if the air flow is restricted even with correct vacuum which is most often due to dirty filters.

Skid error occurs when the aligned forces of skidding flight swing the pendulous vanes from their vertical position. This swinging of the vanes causes the unequal escape of air from the ports to make the gyro precess to the inside of the skid. Upon return to straight-

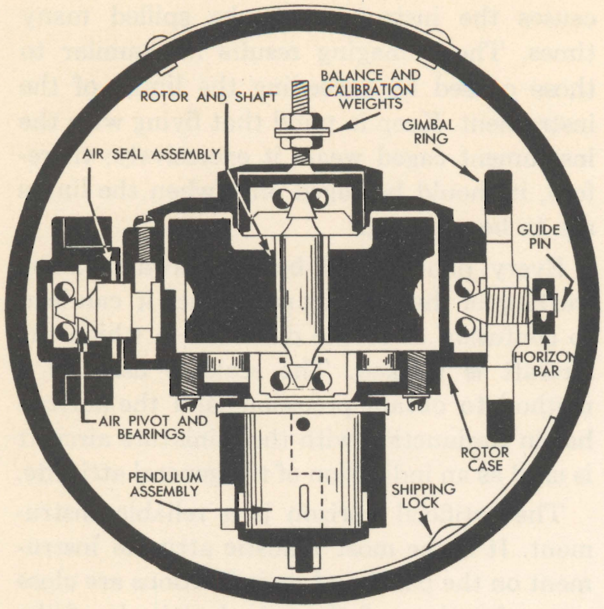


Figure 45. Flight indicator rotor assembly.

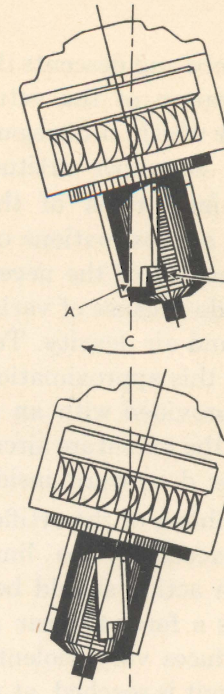


Figure 46. Action of the pendulous vanes.

and-level, coordinated flight, the instrument indicates a turn in the opposite direction of the skid. (See Figure 46.)

Acceleration causes the erecting mechanism to react in such a manner that the horizon bar moves downward. This results in a tendency to dive the aircraft while accelerating. Deceleration causes the erecting mechanism to react in such a manner that the horizon bar moves upward. This results in a tendency to climb the aircraft while decelerating. Both of these errors are proportional to the amount of acceleration and elapsed time while accelerating or decelerating.

Turn error is the result of the swinging of the vanes. The reaction of the instrument is the same as the skid error, but the difference lies in the fact that the motivating force, causing the vanes to swing from the ports, is centrifugal force. Precession of the gyro in a turn is always to the center of the turn. This error causes erroneous bank and pitch indications at varied stages of the turn, and finally cancels itself out at the end of a 360° turn. A small residual error remains. This is caused by the compound action of both the lateral and fore and aft vanes.

Over-all friction errors may cause constant precession that is not quite overcome by the automatic erecting device, and the instrument constantly shows bank or pitch errors or both. Also if the mechanism is unbalanced the gyro precesses away from its erect position. This results in constant errors of pitch and bank. The amount of error depends upon the degree of the unbalanced condition.

PRACTICAL USE OF THE ARTIFICIAL HORIZON

It is necessary to coordinate the artificial horizon with the other flight instruments because of constant errors of indications. In straight-and-level flight, the pilot who relies too much on the artificial horizon will most likely find his flight erratic. A cross-check with the turn-and-bank indicator, directional gyro, and altimeter is necessary. In turns, the pitch error causes improper attitude when the artificial horizon only is used. Constant cross-checking with the other instruments is again

necessary. In climbs and descents the acceleration and deceleration of the actual aircraft causes pitch error which, if disregarded by the pilot, results in improper attitude for the maneuver. The indications of the artificial horizon are only approximations of the exact pitch attitude because of the necessary small changes of attitude because of variation in the air speed, load, and air density. To aid in the interpretation of this approximation, the artificial horizon is provided with an adjustment knob with which the miniature aircraft may be moved upward or downward inside the case.

Spilling or tumbling of the artificial horizon is caused by exceeding the limits of the instrument. Such action should be prevented because it brings a force to bear against the rotor which produces very violent precession until the other limit is reached, at which point there is an abrupt stop in the precession. This may result in cracked, flattened, or loosened bearings, any one of which causes excessive friction and precession. Therefore, if the limits are to be exceeded, the instrument should be caged; although flying with the instrument in the caged position does cause considerable more than normal wear. Exceeding the limits of the artificial horizon may be compared to driving an automobile into a stone wall with immediate damage; flying with the instrument caged can be compared to stopping the same automobile by slamming on the brakes, before hitting the stone wall, thus avoiding immediate damage but causing excessive wear.

The artificial horizon should be uncaged only in level flight. The indications of the instrument depend upon the position of its universally mounted gyro, which if uncaged in an unlevel attitude, tends to remain in an unlevel plane, except for the action of the erecting mechanism. When uncaging the artificial horizon be sure that the instrument is fully uncaged. Unless care is taken to see that this is done, the clamps in the caging mechanism will decrease the maneuvering limits, and the instrument will spill even in a normally safe maneuver.

Special care should be exercised in caging the artificial horizon. Rough forceful caging causes the instrument to be spilled many times. The damaging results are similar to those caused by exceeding the limits of the instrument. Keep in mind that flying with the instrument caged wears it excessively; therefore, it should be caged only when the limits are to be exceeded.

Every pilot should be fully aware of the working of the banking scale since it can lead to confusion as to the direction in which the aircraft is banked. The scale is used as a method to obtain precision, and the horizon bar in conjunction with the miniature aircraft is used as an indication of the general attitude.

The artificial horizon is a reliable instrument. It is the most realistic attitude instrument on the panel and its indications are close approximations of the actual attitude of the aircraft itself. A full understanding of its errors should not create concern but should aid in the interpretation of its indications. Proper care should be taken of the instrument. It should be left uncaged at all times unless its limits are to be exceeded.

ATTITUDE GYRO AND GYRO HORIZON

The electrically-driven Attitude Gyro, Models J-3 and J-4 (Fig. 47), provides the pilot with a constant visual indication of any flight attitude with respect to the earth. During maneuvers, the face of the instrument case with its indices moves in relation to the stabilized sphere with its markings. The relationship between the markings on the sphere and those on the face of the instrument case show the aircraft's attitude with respect to the natural horizon.

The instrument is fitted with a supplementary indication which enables the pilot to determine closely the pitch attitude of the aircraft near the equator on the sphere. Markings on the right side of the sphere are graduated in 1° increments to 10° above and below the equator. A pointer moves along

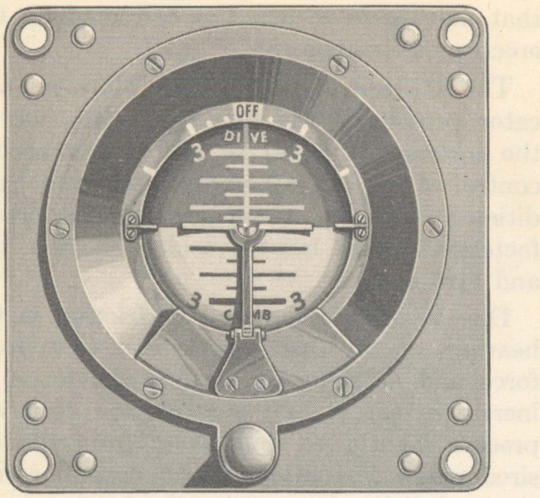


Figure 47—The Attitude Gyro.

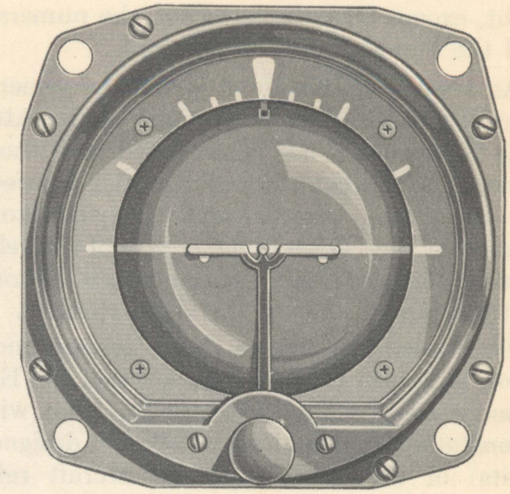


Figure 48—The Gyro Horizon.

these markings to show the degree of dive or climb. The displacement of this pointer over these markings is accelerated or "magnified" as compared to the displacement of the miniature aircraft with relation to the sphere. Thus, greater pitch sensitivity is achieved on this model.

The gyros used in these instruments have complete freedom through 360° of rotation around the roll axis of the aircraft and have effective freedom around the pitch axis. Effective freedom may be explained as follows: Whenever the aircraft approaches a vertical dive or climb attitude, as during a loop, a controlled precession of 180° is mechanically accomplished. This controlled precession should not be confused with tumbling or upsetting of the gyro. After completion of this precession, the Attitude Gyro is still completely operative, and any displacement of the gyro that may have occurred is corrected by the erector mechanism.

To interpret the indications of the Attitude Gyro, the sphere should be visualized as stabilized with reference to the earth and the longitudinal axis of the aircraft as passing through the sphere. As the aircraft maneuvers, the sphere retains its attitude in space or its vertical axis remains perpendicular to the surface of the earth, while the aircraft moves relative to the sphere. When the aircraft is in level flight the 90° roll markings are aligned with the equator on the sphere and the meridian or vertical reference line is aligned with the 0° roll or bank index at the top of the face of the instrument case. The miniature reference aircraft should be aligned with the equator also, although the pilot may have to adjust it to compensate for load conditions or the level flight attitude of a given aircraft. When the aircraft makes a 30° right bank, it banks around the sphere to the right. The miniature reference aircraft banks in like manner. The meridian or vertical line on the sphere indicates the degree of bank by positioning itself near the roll markings on the face of the instrument case. In a left bank the indication is the reverse. When the aircraft makes a straight 20° descent, the aircraft moves up around the sphere so that the pilot looks down on the upper hemisphere or upper half of the sphere. He sees the word "DIVE" slightly above the miniature aircraft. In a 20° straight climb the aircraft moves down and around the sphere so that the pilot is looking up at the lower hemisphere. He sees the word "CLIMB" slightly below the miniature aircraft. Movement about the pitch and bank axes are shown simultaneously by the instrument in the same manner as they were

outlined above individually. The indications in inverted flight are like those in normal flight, except that the lettering, the numerals and the hemispheres are inverted.

As a word of caution it should be remembered that the pitch indications of the Attitude Gyro should not be confused with those of the Gyro Horizon. Relative motion between the miniature aircraft and the "equator" of the Attitude Gyro is the *reverse* of the relative motion between the miniature aircraft and the horizon bar of the Gyro Horizon.

The electrically-driven Gyro Horizon Indicator, (Fig. 48) Models A-1, A-2 and the H-3 (Sperry designation) provides the pilot with a constant visual indication (within designed limits) of the attitude of an aircraft relative to the earth in pitch and roll. The presentation of the attitude of the aircraft on the face of the Gyro Horizon Indicator is not like that on the Attitude Gyro but can be compared rather, to the attitude indications of the air-driven Artificial Horizon. Using the indications of the Gyro Horizon during instrument flight is exactly like using the natural horizon during contact flight. The miniature aircraft of the instrument represents the aircraft, and the horizon bar represents the natural horizon. Thus, the position of the miniature aircraft relative to the horizon bar reproduces the attitude of the aircraft relative to the natural horizon.

The indications of the Gyro Horizon Indicator are limited by design to 27° in both dive and climb, and to 90° in right and left bank. At the pitch limits, the horizon bar reaches the extremes of visibility through the glass face; roll, however, can be approximated beyond the 90° limits. These limitations, however, do not apply to the gyro itself which has complete freedom through 360° of rotation around the roll axis of the airplane, and has effective freedom around the pitch axis. Thus, when the aircraft approaches a vertical dive or climb attitude, as during a loop, a controlled precession of 180° is mechanically accomplished. This instrument is non-tumbling and the controlled precession should not be confused with tumbling or upsetting the instrument. After completion of this controlled precession the Gyro Horizon is completely operative, and any displacement of the gyro that may have occurred is corrected by the erector mechanism.

The Attitude Gyro and Gyro Horizon Indicator provide stable planes of reference on the instrument panel to aid in the precise control of the aircraft under instrument conditions. However, there are two important factors the pilot must consider: *erection time* and *gyro stability.*

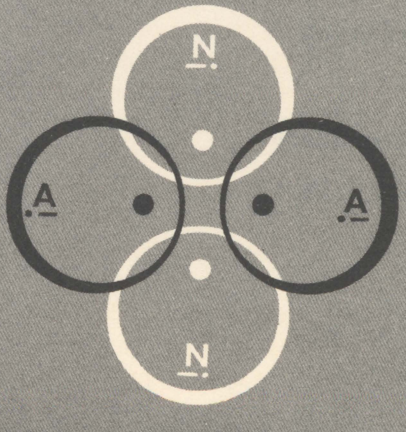
Due to a slight amount of friction in the bearings of the instruments and centrifugal force and acceleration causing the forces of inertia to act upon the rotor, the gyro will precess slightly or drift away from the desired plane of rotation under certain conditions of flight. An erection mechanism is incorporated in the instruments to correct this condition and bring the gyro back to its proper position. The average erection time is 3 to 4 minutes; however, the gyro, being, slightly pendulous, may at times assume an initial position 40° to 50° from the vertical. Completion of the erection cycle may then require up to 14 minutes. (Erection rate and pendulosity are both kept at very low values in order to minimize the errors produced in turns or other flight maneuvers introducing acceleration).

In regard to Gyro Stability the normal rotor speed is approximately 23,000 rpm. At this speed the gyro is most efficient since erection rate and turn compensation (gyro tilt) are designed for the normal gyro moment. To attain this velocity from the initial start requires about 5 minutes. This does not mean that the gyro has insufficient stability for use at lesser speeds, but merely that the efficiently is reduced by slight increases in both erection rates and turn errors. The gyro motor accelerates rapidly and, except under extremely cold (temperature) starts, sufficient stability for "scramble" take-offs is provided within 1 to 1½ minutes after start.

In some models a small shutter is incorporated on the face and provides a ready indication or rotor revolution. Shutter operation at the rate of one blip every six seconds indicates sufficient gyro stability for emergency use.

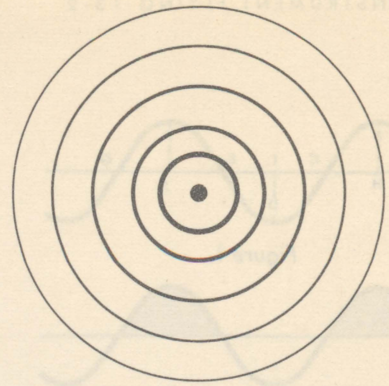
Part 2

Navigational Aids, Methods, and Procedures



Outline to Part 2

CHAPTER THIRTEEN



Basic Radio

Since radio communication is an absolute necessity for instrument flight, the pilot should have a knowledge of the principles of radio and be familiar with the capabilities and employment of the airborne radio equipment used by the Air Force.

Communication is possible by means of sound, light, and electricity. One thing in common to these three methods is that energy is transmitted by waves. In discussing waves it is necessary to make use of terms common to all types.

A wave is a spurt of energy traveling through a medium by means of vibrations from particle to particle. When a stone is dropped into a pond, the energy of motion of the stone disturbs the water, causing the water to rise and fall. The ripples (or the energy) travel outward from the place where the stone struck the water, but the water itself does not move outward. The rise and fall of the water above and below the normal undisturbed level can be pictured as a curved line, as shown in Figure 1. Normally the "per second" is dropped, and the frequency is spoken of as, for example, two cycles.

In discussing waves it is necessary to make use of terms common to all types:

A *cycle* is a complete series of events. In Figure 1, a cycle is represented by the portion of the wave from A to E, from B to F, from C to G, or between any other two points encompassing exactly one complete series of events. Since the number of cycles runs into high figures when discussing radio frequencies, larger basic units are used. Thus, 1,000 cycles equals one kilocycle (kc.), and 1,000 kilocycles equals one megacycle (mc.).

The number of cycles that are completed in one second is called the *frequency* of a wave. If two cycles are completed in one second, the frequency of the wave is two cycles per second.

The linear distance of a cycle is known as the *wavelength*. Therefore, in Figure 1, the portion of the wave from A to E, expressed in meters, feet, miles, or any other measurement of length, is the wavelength of that particular wave.

The *amplitude* of a wave is the linear distance from the normal level of the wave to its highest point, e.g., B or F (Figure 1), or from the normal level to the lowest point. In Figure 1, the amplitude is represented by the line BH, ID, or FJ.

One of the most elementary methods of communication is by sound. Man first communicated with his neighbors by voice; then he progressed a bit further when he transmitted sound over greater distances by beating on a log or a drum. Sound waves are produced by setting the air in motion and are

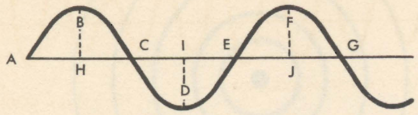


Figure 1.

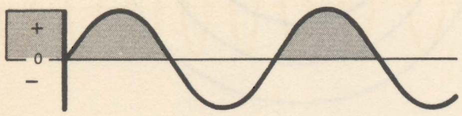
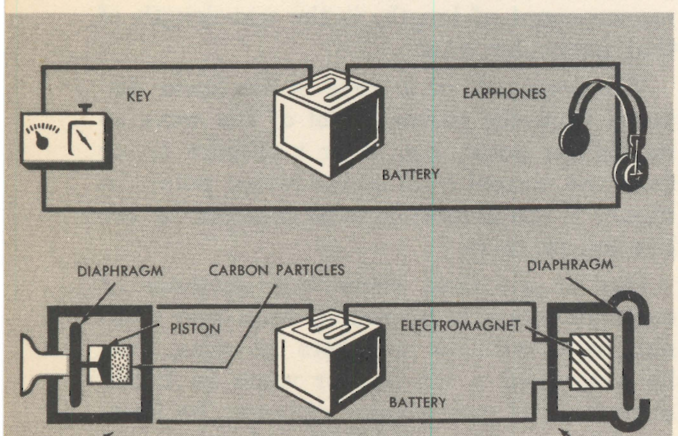


Figure 2.

actually the compression and rarefaction of air particles. The speed of sound waves in air at sea level is 1,087 feet per second (761 mph), and the frequency varies from approximately 20 to 2,000 cycles.

Communication by light waves has been used in the past and is used today in many ways. The traffic light at the corner, the reflection of the sun's rays by a mirror, and the use of blinking lights are examples. Light waves travel at 186,000 miles per second and have a frequency of 375 to 750 million megacycles. One disadvantage in using light waves for communication is the difficulty in seeing the source at all times.

Communication by electricity is one of the best methods of transmitting information from one place to another. All matter in the universe is made up of atoms, which are composed principally of electrons (negatively charged particles), protons (positively charged particles), and neutrons. When electrons are



Figures 3 and 4

made to move through a conductor, electricity is said to be flowing. A direct current (d.c.) results when the electrons flow in only one direction. An alternating current (a.c.) results when the electrons flow in one direction for a time and then flow in the opposite direction for a time, the reversal being continuous. An alternating current can be represented as a continuous change of direction of flow of current (from plus to minus) as shown in Figure 2.

The telegraph, which was the first electrical means of communication, employs the following materials:

1. *Key.*
2. *Wire.*
3. *Source of energy.*
4. *Reproducer.*

The materials are connected together as shown in Figure 3.

When the key is pressed down, the current starts to flow and causes a "click" in the sounder. The use of a dash-dot code permits the transmission of messages. Two of the disadvantages of the telegraph are that a connecting wire is required and voice is not used.

The telephone, which provides means for transmitting voice over wires employs the following materials:

1. *Microphone.*
2. *Wire.*
3. *Source of energy.*
4. *Reproducer.*

The type of microphone commonly used in aircraft is the carbon microphone. Carbon granules have the property of allowing more current to flow when the carbon particles are pressed together than when they are loosely packed. Figure 4 shows a carbon microphone schematically used in a telephone circuit.

Sound waves entering the microphone strike the diaphragm causing it to vibrate. This vibration moves the piston which packs the particles of carbon together or allows them to remain farther apart. This alternate packing and unpacking causes a pulsating current to flow through the circuit. Thus, voice causes a varying amount of current to

flow, and the varying current increases and decreases the strength of the electromagnet in the earphone or loudspeaker. The change in strength of the electromagnet causes the diaphragm to vibrate which in turn starts the air moving, setting up a sound wave.

The radio permits communication over great distances without the use of wires, and is based upon the generation of radio waves by a transmitter and the reception of these waves by a receiver.

When a current flows through a wire, a magnetic field is built up around the wire. If an alternating current flows through a wire, the magnetic field alternately builds up and collapses. An alternating current of high frequency is used to generate radio waves, which are emitted by the building and collapsing of the magnetic field around a conductor (antenna). The frequencies used in radio range from 50 kilocycles to 10,000 megacycles and higher. Radio waves are well suited for aviation purposes since they travel far and at the speed of light (approximately 186,000 miles per second).

Fundamentally, a radio signal is transmitted by *generating* a radio frequency current and connecting it to an antenna suitable for radiation of the particular frequency.

In order to transmit intelligence, this radiated signal must be altered in some manner and the alterations decoded at the receiver. Code is transmitted by breaking the signal up into dots and dashes. Voice is transmitted by molding, or modulating, the signal to the vibrations of the voice. The amplitude, or strength, can be molded, or the frequency can be made to change over a small range of frequencies. The first method is called "amplitude modulation" and the second is called "frequency modulation." Amplitude modulation is generally used in aircraft radios (Fig. 5).

An unmodulated signal is called a continuous wave (CW) signal. The principal use of CW signals is in the transmission of International Morse Code. A modulated signal is commonly referred to as a modulated carrier wave (MCW). If a steady tone, instead of voice, is used to modulate the transmitted

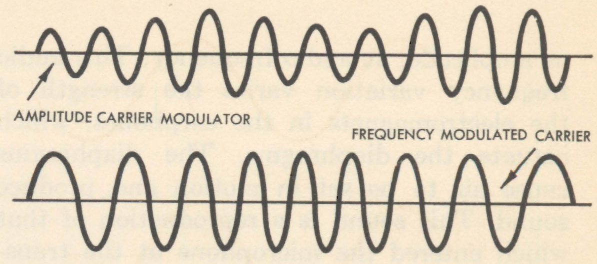


Figure 5.

signal, the signal is still a MCW signal, commonly called a tone signal. Figure 6 shows a simplified functional illustration of a radiotelephone transmitter.

Radio waves set up minute currents in receiving antennas, just as an alternating current is set up in any conductor which is placed near another conductor that carries an alternating current. To receive a radio signal there must be some method of *selecting* the desired signal and rejecting the many undesired signals. This process is called tuning. The tuning circuit in the receiver is adjusted to *resonance* with the frequency of the desired signal; other frequencies are rejected by the tuning circuit, and the desired one is allowed to flow to the detector.

The radio frequency current of the desired signal is of too high a frequency to actuate the earphones. The audio frequency current which was used in modulating the signal at the transmitter is needed to drive the earphones in order that the transmitted voice may be reproduced. The detector rectifies the alternating signal current and allows a pulsating direct current to flow to the earphones. This current is pulsating at radio frequency but it also is varying in strength,

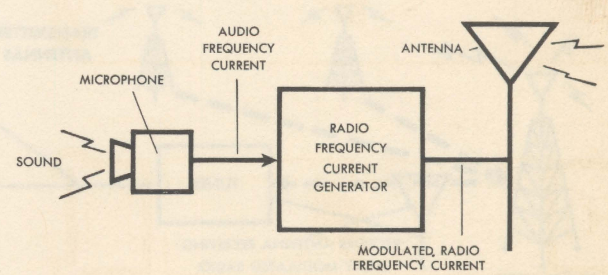


Figure 6.

or amplitude, at audio frequency. This audio frequency variation varies the strength of the electromagnets in the earphones, which actuate the diaphragms. The diaphragms cause air to be set in motion and produce sound. This sound is a reproduction of that which entered the microphone at the transmitting station.

General Nature of Low Frequency Radio Wave Propagation

When a radio wave leaves an antenna it spreads in all directions. Part of the radiated energy travels along near the ground and is "conducted" around the surface of the earth until it is absorbed or plays out. This portion of the radiation is called the ground wave. The remainder of the energy is called the sky wave or space wave (Fig. 7). It is radiated upward into space and would be lost completely were it not for the reflecting layers of highly charged particles that exist some 30 to 250 miles above the earth's surface. These layers reflect or refract a portion of the radiation back to earth and enable signals to be received at distant points. These layers are known as the ionosphere. The ionosphere varies in height above the earth's surface with the season of the year; during the winter in the north Polar region, it may be as low as 30 miles above the earth's surface; during summer at the equator, it may rise to as high as 250 miles above the earth.

Skip Distance

The distance between the transmitting antenna and the point where the sky wave first returns to the ground is known as the skip distance. The area between the point where the ground wave becomes too weak for reception and the point where the sky wave first returns is known as the skip area, or skip zone. Since the radiation received from the sun varies the position of the ionosphere, there is a great change in skip distance at dawn and dusk. During these times fading of signals is more prevalent. (Figure 8).

Effect of All Matter Upon Radiation

All matter within the universe has a varying degree of conductivity or resistance to radio waves. The earth itself acts as the greatest resistor to radio waves; the part of the radiated energy that travels near the ground induces a voltage in the ground that subtracts energy from the wave. The result is that the ground wave is attenuated, or decreased in strength, as the distance from the antenna becomes greater. The atmosphere acts in the same way in that the molecules of air, water, and dust absorb the energy of radiation. Other matter on the surface of the earth also acts to absorb radiation, such as trees, buildings, and mineral deposits.

Effect of Static Upon Low and Medium Frequency Reception

Everyone who has listened to a radio is familiar with the effects of static. This disturbance may be broken into two types, man-made interference, and natural interference. An example of man-made interference is that caused by an ordinary electric razor. Each small spark, whether it be generated by a spark plug, contact point, or brushes on an electric motor, is a source of radiation. All frequencies from zero to approximately 50 megacycles are transmitted from each spark and consequently add to any reception within

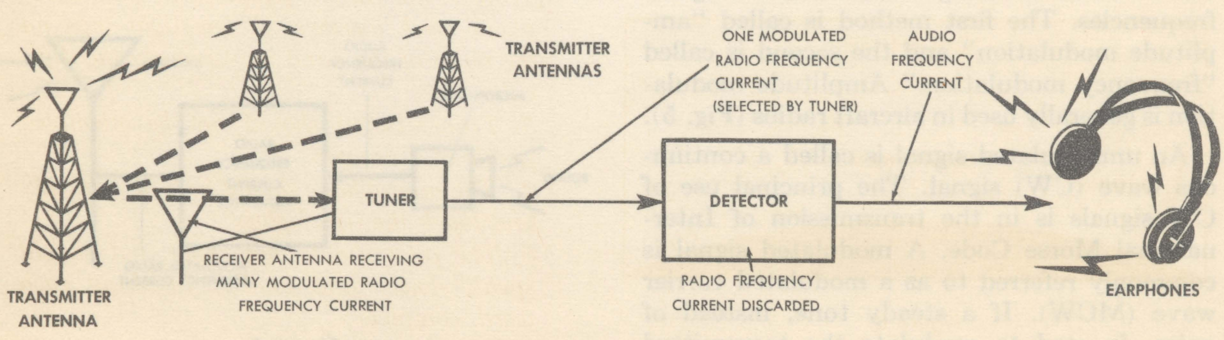


Figure 7.

this range. Natural static may be divided into two types, called atmospheric static and precipitation static. Interference which originates from natural sources away from the aircraft is known as atmospheric static. Interference which originates from electrostatic discharges from the aircraft, resulting from aerological conditions, is known as precipitation static.

General Nature of High Frequency Propagation (3,000 to 30 mc.)

The attenuation of the ground wave at frequencies above approximately 3,000 kc is so great as to render the ground wave of little use for communication except at very short distances. The sky wave must be utilized, and since it reflects back and forth from sky to ground, communications may be maintained over long distances (12,000 miles, for example, With the use of the higher frequencies, the absorption of radiation by the atmosphere is reduced; however, the higher the frequency becomes, the less is the return of the sky wave near the vertical.

General Nature of Very High Frequency (VHF) Propagation (30 to 300 mc.)

There is practically no ground-wave propagation at frequencies above about 30 megacycles and there is ordinarily no reflection from the ionosphere, so that communication is possible only if the transmitting and receiving antennas are raised sufficiently above the surface of the earth to allow the use of a direct wave. This type of radiation is known as line-of-sight transmission. Thus, VHF communication is dependent upon the position of the receiver in relation to the transmitter. When using airborne VHF equipment, it is of utmost importance to understand the factors limiting the range of communication. The range of VHF transmissions is normally about one-third more than an actual line of sight. This range can be determined by a simple formula: Range (miles) = square root of altitude (ft) $\times 1.41$.

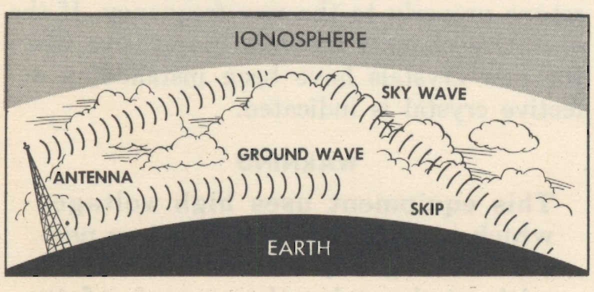


Figure 8.

Listed below is the approximate range for VHF transmissions over flat terrain:

AIRCRAFT ALTITUDE	RANGE
1,000 feet	55 miles
1,500 feet	65 miles
2,000 feet	75 miles
2,500 feet	85 miles
5,000 feet	110 miles
10,000 feet	150 miles
15,000 feet	185 miles
20,000 feet	210 miles
30,000 feet	255 miles
40,000 feet	290 miles
50,000 feet	320 miles

High-Frequency Command Set SCR-274N

Command set SCR-274N is operated by the 24-volt aircraft electric system; the transmitter and receiver are separate units. As many as four transmitters are available for use, usually two are installed in the aircraft. The transmitter desired is selected by use of the TRANSMITTER SELECTION switch on the transmitter control box. The transmitter is turned on and off by means of the TRANS-POWER switch on the control box. The TONE-CW-VOICE switch allows choice of three types of transmission. Range of transmission is approximately 25 miles on voice, 50 to 75 miles on tone, and 100 miles on CW. When transmitting, the pilot should keep in mind the following points:

1. *If the antenna is touched while the microphone button is depressed, a severe shock may be received.*
2. *Sometimes, particularly after rainy weather, the carbon particles in the microphone stick together. A few light taps on the palm of the hand may remedy the difficulty.*
3. *Transmission should not be attempted inside of a hangar.*
4. *The microphone should be held vertically and touch the lips lightly.*
5. *The pilot should not shout, but should speak slowly and loudly, finishing each word completely.*

Either two or three command receivers are used in most aircraft. The receivers that may be available operate in the frequency bands of 3 to 6 mc, 190 to 550 kc, and 6 to 9.1 mc. All the controls for the receivers are located on the receiver-control box, which is divided into sections, one section for each receiver. A receiver is turned on and off by operation of the CW-OFF-MCW switch. The INCREASE OUTPUT knob controls the volume, and the A-B switch selects the desired output channel. If the headset jack is plugged into the interphone jackbox or the A TEL socket, the A-B switch should be placed on A. This is the normal setting. On the receiver itself is a small knob labeled "ALIGN INPUT." By adjusting this knob for maximum background noise, better reception can sometimes be obtained. The RANGE-VOICE-BOTH switch is used to select range signals or voice signals when simultaneous broadcasts are being made.

Command Set AN/ARC-3

Most USAF aircraft are now equipped with radio set AN ARC-3, which provides the pilot with a conveniently operated command radio, operating on any of eight automatically selected frequency channels. The set gives static free communication over line-of-sight distances within the frequency range of 100 to 156 megacycles.

OPERATION. The equipment is started by depressing any of the eight buttons labeled "A" through "H". Power is applied to the transmitter and the receiver and both are automatically tuned to the frequency of the channel selected. The set normally requires 30 to 45 seconds for warm-up; during the latter part of this period when an audio tone, which is heard in the headset, stops, the set is tuned and ready for use.

When the microphone button is pressed for speaking into the microphone, a speech side tone should be heard. If there is no side tone, check the equipment to ascertain whether a crystal is installed in the selected channel. In most multiseat aircraft, the interphone jackbox is used to control the volume. In fighter aircraft a separate control unit is provided. A keying button is located at the bottom of the control box, which may be used for transmission of tone signals for use of VHF D F homing stations or for sending messages in code. Use of the tone button will not increase the range of transmission.

To turn off the set, depress the OFF button and the small lock release located adjacent to it simultaneously. The lock is provided to prevent inadvertent turn-off when selecting channel buttons near the OFF button.

Emergency Operation

Trouble in many parts of the set may result in its failure to tune the desired channel. Mistuning may be recognized by a lack of reception, or absence of side tone from the microphone. Before attempting to make any repairs, first push another channel button, and when the tuning cycle tone ceases, push the original channel button. This procedure should remedy most minor mistuning difficulties; however, if the set mistunes repeatedly, check the operation of the other channels. If any channel is found to be operative, it may be used for the desired frequency by performing the following changes:

1. *Transmitter.*
Move the crystal corresponding to the desired frequency into the operative channel position.
2. *Receiver.*
Move the crystal for the desired frequency into the operative channel, and set the thumbwheel of this channel to the desired frequency.
3. *Control box.*

Push any button on the set other than that of the operative channel; then after the tuning cycle is completed, depress the button of the operative channel. This allows the set to retune properly to the new frequency. If the operative channel becomes inoperative when the new crystals have been installed, a defective crystal is indicated.

WARNING

This equipment uses high voltages which are capable of injury to a person making adjustment to the set without observing the normal safety precautions.

CHAPTER FOURTEEN

Radio Range

Across the United States and Canada stretches a series of well defined pathways of radio signals, constituting aerial highways, properly called airways. The signals which form the basis for these airways emanate from a network of several hundred ground transmitting stations which function for navigation and communication purposes during both visual and instrument flying conditions. An increasing need for radio navigation as a result of increased instrument flying makes it essential that the Air Force pilot understand the construction, operation, and use of radio ranges and the additional aids used in conjunction with radio range flying.

Radio navigation is very similar to visual navigation in that following a railroad when flying from one visual check-point to another. The greatest difference between the two is the substitution of aural signals for visual references and check points.

CLASSIFICATION

Two types of low-frequency ranges in general use in the United States today are the loop (L) range and the Adcock (A) range and are named for the type antenna used on each. The Adcock is frequently referred to as the transmission line (TL) range. The majority of the low-frequency ranges utilize the 200- to 400-kilocycle band; however, there are a few homing stations and many ranges that fall between 400 and 550 kilocycles. The following power classifications are used on loop and Adcock ranges:

1. *Loop ranges and Adcock ranges which have power of 150 watts or more are called RL and RA respectively.*
2. *Loop and Adcock ranges which have medium powers of 50 to 150 watts are called MRL and MRA respectively.*
3. *Loop ranges of less than 50 watts are called ML. (There are no Adcock ranges of less than 50 watts.)*

The Loop Range

The directional transmission of a range is dependent upon the shape of the transmitting antenna. The antenna of the loop range consists of two rectangular-shaped loops constructed at right angles to each other. Poles suspend the loops in the vertical plane. The dimensions of the loop are about 40 x 300 feet. One of these antennas is the N-antenna since it is used for broadcasting the N-signal. The other antenna which is used for broadcasting the A-signal is the A-antenna. When voice is being transmitted, both antennas are used.

The transmitter produces a modulated carrier wave with an audible tone of 1020 cycles per second. This solid tone is fed by a keying device alternately to the two antennas in this sequence: dash, dot, dot, dash, dash, dot, dot, dash, etc. This results in an N-signal (dash dot) on the N-antenna and an A-signal (dot dash) on the A-antenna. Actually a solid tone is broadcast, but because of the directional quality of each antenna, a well defined N- or A-signal is created in the quadrants and the solid tone can be heard only when the signals from the N- and A-antenna are received with equal intensity. Once each 30 seconds the A- and N-keying is discontinued and the station call letters are transmitted twice, first over the N-antenna and then over the A-antenna.

THE SIGNAL PATTERN. The two vertical portions of the loop antenna radiate signals that are 180° out of phase. It is evident that at any point in line with the two vertical portions of the loop the radio waves received are most nearly in phase (owing to the greater difference in distance travelled). This condition gives the maximum intensity of the transmitted signal. At any point on a line through the hole (perpendicular to the plane of the loop) the signals are 180° out of phase (since the distances from each side of the loop are equal). This condition gives minimum intensity of the transmitted signal. The area of transmission of a single loop covers a figure-eight pattern, having the strongest signal in line with the plane of the loop and signals growing progressively weaker on either side (Fig. 9).

By utilizing two loop antennas at right angles to each other, a pattern is produced with two figure-eight patterns at right angles to each other. Because of the keying of the signal, the directional quality of the antennas, and the relative position of the two figure-eight patterns, the following zones are formed:

1. *The quadrants These are sectors where one signal predominates.*
2. *The on-course (or beam) This is a line where the N- and A-signals blend together to form the 1020-cycle solid tone.*
3. *The bi-signal zone—This is the area of overlap of the two figure-eight patterns. The on-course is in the center of this zone. On either side of the on-course the N- and A-signals are heard with unequal strengths. In the N-quadrant the N is distinguishable as an N and A appears to form a solid background tone. In the A-quadrant the A is distinguishable as an A, and the N appears to form a solid background tone. The width of the bi-signal zone and its area are dependent upon receiver sensitivity and volume control.*
4. *The clear-signal zone—This is the area outside of the area of overlap. In the clear signal zone, the quadrant signal is heard with no background tone.*
5. *The cone of silence—This is an area over the station in which no signal is heard. It is noted that the first identification signal being broadcast over the N-antenna follows the same volume intensity pattern as the N does, and the second identification signal being broadcast over the A-antenna follows the same volume intensity pattern as does the A.*

Night Effect. Night effect sometimes causes the loop-type range to be unreliable at night beyond about 30 miles. This is due to the effect of the sky waves radiated from the horizontal portions of the loop. These sky waves are reflected by the ionosphere and the reflected waves come back to earth at some point beyond 30 miles from the station. A reflected wave may or may not be in phase with the ground wave at the same point, thus resulting in increase or decrease in the intensity of the N or A. Because of the shifting of the ionosphere at sunset and sunrise, erratic phase combinations occur which result in an apparent swinging of the position of the on-course.

The Adcock (TL) Simultaneous Range

The Adcock range which was built to overcome the disadvantages of the loop-type range, has replaced the loop-type range at important air terminals and airway intersections.

The Adcock range employs sturdy steel

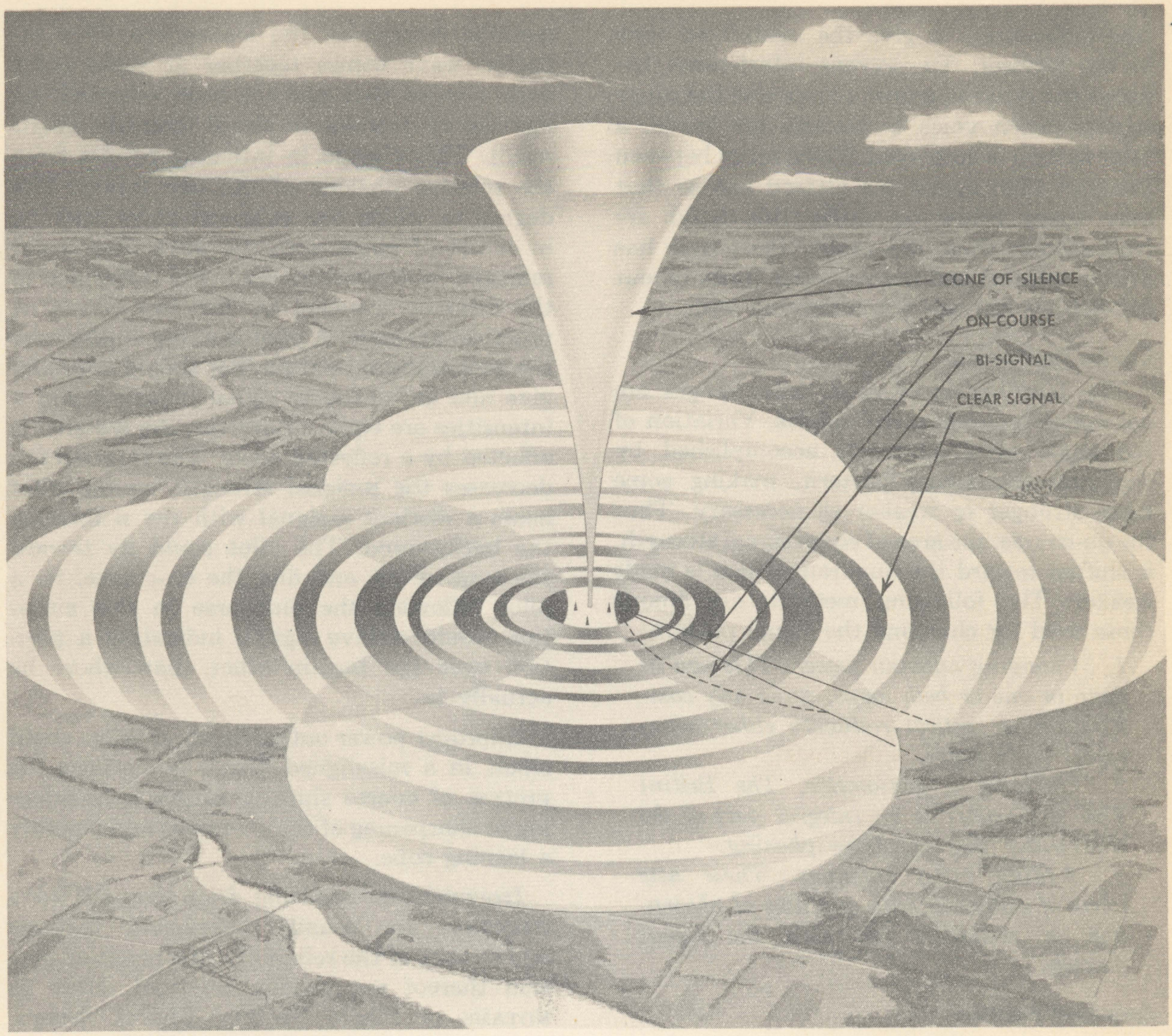


Figure 9.

towers approximately 125 feet high (called vertical radiators), instead of the suspended loops. Two towers placed approximately 800 feet apart and fed alternating current 180° out of phase radiate a figure-eight pattern, essentially the same as the pattern made by the vertical portions of a loop. The transmission lines from the transmitter to the towers are buried and shielded — thus reducing the radiation of sky waves and eliminating night effect. By placing two such pairs of towers at right angles to each other, the same signal zones are formed as were formed by two loops. A fifth tower, located in the center of the other four, transmits a constant carrier wave that is used for the simultaneous voice facility.

The center tower broadcasts omnidirectionally a continuous carrier wave on the stations assigned frequency. The outlying towers broadcast an unmodulated carrier wave to form the signal pattern, always using a frequency of 1.02 kc higher. For example a station with an assigned frequency of 250 kc broadcasts a signal from the outlying towers on a frequency of 251.02 kc. Interference between the two frequencies creates a beat-frequency of 1.02 kc or 1020 cycles per sec.

(the difference), to give the modulated tone in the headset. To prevent interference between the range operator's voice and the range signals, when voice broadcasts are made, a filter system is employed. Voice tones between 850 and 1225 cycles are filtered out so that only tones below or above this band are transmitted; thus, the range signal tone has a clear channel and normal voice tones (about 300-800 cycles) are not interfered with.

Course Positioning

The four beams of most radio ranges are not evenly spaced at 90° angles. Variation of the angle of a course is accomplished by changing the signal pattern, making some lobes stronger or weaker as necessary. Thus the on-course, the area of equal signal strength, is shifted toward the quadrant which is made weaker. The following methods are among those used for changing the signal pattern:

1. *Changing antenna power. This can be done in one or both loops, or in any combination of vertical radiators either separately or in pairs.*
2. *Utilizing a goniometer. The Bellini Tosi goniometer is an integral part of the transmitter that regulates phasing.*
3. *Adding extra antennas. These new parts of antennas with qualities of absorption or radiation can alter the signal pattern.*

Quadrant Position

In the United States the quadrant containing the true inbound bearing of 180° is designated as the basic N-quadrant. If a range leg falls on this bearing then the basic N quadrant is the northwest quadrant.

Range Irregularities

There are several types of range irregularities which bear such titles as swinging beams, split beams, bent beams, multiple beams, false cones, and misaligned beams. Causes of these irregularities can be grouped under the following two general headings: (1) reflection of radio waves; and (2) mechanical defects of the transmitter.

A radio wave can be reflected or absorbed by many objects such as: terrain, ore deposits, metallic structures, the ionosphere. If a reflected wave comes together at some point with a wave that has not been reflected, an increase or decrease in signal intensity might result. This change in intensity results from the relative phasing of the two waves. The degree to which the reflected wave may be in or out of phase with the wave that is not reflected is dependent upon the difference in the distance traveled by the two waves. A practical example: A pilot is flying a path over the geographical location that should normally give him an on-course signal (where N and A intensities are equal); however, the N-signal is affected by a reflected wave. The interference decreases the N-signal strength, so the pilot hears a distinct A-signal with the N forming the background. The pilot could fly toward the N-quadrant and find the on-course. So a pilot following the on-course in this situation would receive signals indicating a position over the terrain other than where he actually is.

Improper power output in an antenna could result in a misaligned beam. Sometimes the process of course shifting causes a broadening or sharpening of the on-course and possibly a leaning cone.

Irregularities resulting from ground wave reflection are usually permanent features and notices of the reliability of a range or portion thereof are usually reported either in NOTAMS or Radio Facility Charts. Irregularities caused by sky wave reflection can be expected on any loop range at night. Irregularities resulting from mechanical malfunction are usually temporary and are quickly corrected; however, they might be reported either in NOTAMS or the remarks section of the hourly teletype report.

CAA AUTOMATIC RANGE MONITORING DEVICES

The function of a radio range monitor unit is to recognize certain abnormal or erroneous conditions of radio range operation, and automatically provide warning that such abnormal conditions exist. Two types of warnings are involved, the primary being the transmission

of an aural signal on the range frequency for the benefit of the pilot, and a secondary or special warning, not observed by the pilot, transmitted for the benefit of the communicator at the control station, who immediately will initiate corrective action.

The most important abnormal conditions detected are a shift in range course alignment beyond 3° and a failure of the A- and N-keying device. When either of these occur, the monitoring device interrupts the range signals and keys the Morse Code letters UUU once during each standard keying cycle.

NONCONFORMITY OF THE RECEIVED SIGNAL PATTERN

Manipulation of the receiving set, the type of equipment, attitude of the aircraft, the type of weather being flown in, and procedures can cause the received signal pattern not to conform with the transmitted pattern. These are not to be confused with normal range irregularities. A few factors to consider are:

1. *Volume control—Turning the volume control up or down, in effect, increases or decreases the size of the lobes of the pattern. It is noted that the position of the edge of the background is controlled by the position of the volume control. Overloading the receiver can cause the strongest part of the signal to spill resulting in a reversal of signals. Automatic volume control tends to broaden the width of the on-course. Filters decrease the volume.*

2. *Type of equipment—The type of antenna might give a slightly distorted pattern because of directional reception qualities. On account of its position, the antenna might be affected by refraction of the waves around the leading edge of the wing, or might be blanked out. Banking the aircraft when it is in or near the on-course can cause false signals from a loop range.*

3. *Static—Precipitation static has the effect of reducing the size of the pattern and making the signals unintelligible. One countermeasure is to use the shielded loop antenna of the radio compass for radio range reception.*

4. *Improper procedures may often lead to confusion. A few important points to be considered are: improper tuning, improper volume setting, improper interpretation of signals, flying wrong heading, disregarding wind, using poor orientation procedure, and assuming a position without positive proof.*

ADDITIONAL RADIO AIDS

The Z-marker is a range station location beacon. It gives the pilot positive identification of his position over the cone of silence. It is a very high-frequency transmitter utilizing a normal output of five watts, transmitting an unkeyed signal, modulated with a 3000 cycle sec. tone on a frequency of 75 megacycles. It sends a directional pattern directly above the station, about one-half mile in diameter and about 1000 feet vertically above the terrain. The directional antenna is a combination of 4 dipoles forming a horizontal cross placed above a horizontal 30 x 3 foot counterpoise. Reception of the signal requires a 75 megacycle marker beacon receiver, which turns on an amber light on the instrument panel to give a steady glow when in the transmitted pattern. To receive the aural 3000 cycle tone, additional receiver equipment is necessary; this extra equipment is not usually installed in Air Force aircraft.

The fan marker (FM) is used to tell the pilot his exact position along the range leg. It is also used in "holding" and "stacking." It differs from the Z-marker only in the pattern produced and the coded signals. The FM radiates an elliptical-shaped pattern about 10 miles in width and 3 miles across. It utilizes a 100-watt power output. The construction is also the same as the Z-marker except that the dipoles of the fan marker are laid end to end for the purpose of creating the elliptical fan-shaped signal pattern. At some installations, a bone-shaped fan marker is produced by radiating two adjacent lobe patterns. This pattern is desirable in that it provides a well defined point directly on course and a wider indication to either side of the beam. The same 75-megacycle receiver used for Z-marker reception is used to receive the fan marker. The

pilot's indication is a series of dashes on the amber light, corresponding to the number of the range leg on which the FM is located. If there are two FM's on the same leg, the coding of the outer FM is preceded by two dots.

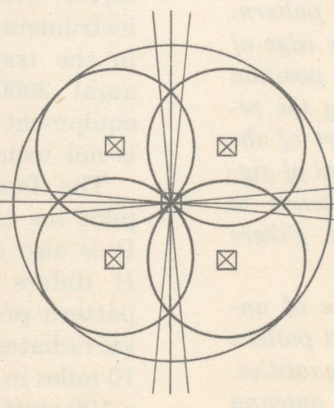
The non-directional radio beacon is a homing station used with radio compass equipment. It is merely a non-directional transmitter broadcasting a modulated, coded tone on a frequency between 200 and 550 kilocycles with a power up to 400 watts. The code consists of identification signals constantly repeated or an alternation of solid tone and identification signals.

ORIENTATION

Range orientation is accomplished by determining the aircraft's position through interpretation of aural signals from a radio range station. Fundamentals of range orientation include:

1. *Range identification (frequency and call letters).*
2. *Quadrant identification.*
3. *Quadrant fade or build.*
4. *Beam interception and identification.*
5. *Beam following.*
6. *Station (cone) recognition.*

Proper use of the range and an understanding of its peculiarities tend to make instrument pilotage easier and navigation problems simpler. The signal received and its interpretation are dependent upon the type of station, its power, its location in relation to terrain features, the time of day, the atmospheric conditions, the distance the received signal has traveled, the geographical location of the aircraft, the type of equipment being used, the attitude of the aircraft, manipulation of the receiver, and the general procedures used.



CHAPTER FIFTEEN

Voice Procedure

Voice communication in the Air Force is often complicated by poor enunciation, incorrect use of standard phraseologies, improper use of the microphone, and unnecessary chatter. Conditions in an airborne aircraft do not compare favorably with those in a radio broadcasting studio where elaborate precautions are taken to ensure audibility and exclude outside noise. Intelligibility under operating conditions requires the most efficient possible use of the radio equipment, the voice of the speaker, and the ear of the listener. Efficient radio communication requires the proper use of voice, radio equipment, standard terms and phrases.

USE OF THE RADIO EQUIPMENT

Hand held microphones should be held directly in front of the mouth in order to speak directly into rather than across the microphone; and it should be as close to the mouth as possible without interfering with the movement of the lips. The microphone should actually touch the lips slightly to ensure maximum loudness and exclude some of the interference from outside noise.

Throat mikes should be worn so that the two buttons either straddle the "Adam's apple" or remain slightly above it. The strap should be adjusted tightly enough to be just short of uncomfortable. A slight displacement of the buttons from the correct position, or the least slackness in the straps, markedly lower the intelligibility of the signal.

ENUNCIATION

Thorough tests have shown that the use of a normal tone in speaking into the microphone is not too satisfactory. The voice should be raised as much as possible without straining or distorting it because the spoken sound must be louder than the outside noises that filter into the face of the microphone. The amplifier raises the voice level with the corresponding increase in the level of the outside noises. Speech should be distinct. Pronunciation should not be distorted but every syllable of every word should be emphasized, without "ers" or "ughs" between words. In speaking a complete sentence, use the natural sentence rhythm and intonation, but do not drop the voice.

Phonetic Alphabet

Whenever it is necessary to identify any letter of the alphabet the standard phonetic alphabet, given on the following page, is used.

LETTER	SPOKEN AS	LETTER	SPOKEN AS
A	ABLE	N	NAN
B	BAKER	O	OBOE
C	CHARLIE	P	PETER
D	DOG	Q	QUEEN
E	EASY	R	ROGER
F	FOX	S	SUGAR
G	GEORGE	T	TARE
H	HOW	U	UNCLE
I	ITEM	V	VICTOR
J	JIG	W	WILLIAM
K	KING	X	XRAY
L	LOVE	Y	YOKE
M	MIKE	Z	ZEBRA

Numbers. When saying numbers, enunciate each number clearly in the following manner:

Number	Spoken As	Number	Spoken As
1	WUN	6	SIX
2	TOO	7	SEVEN
3	THU-REE	8	ATE
4	FOWER	9	NINER
5	FI-YIV	0	ZERO

For example, 87350 is spoken as ATE SEVEN THU-REE FI-YIV ZERO. An exception to the rule for saying numbers separately occurs when giving ceiling heights, flight levels, and upper-air levels, for example:

Altitude	Spoken As
1,000	WUN THOUSAND
11,000	ELEVEN THOUSAND
6,500	SIX THOUSAND FI-YIV HUNDRED
24,500	TOO FOWER THOUSAND FI-YIV HUNDRED
13,000	WUN THU-REE THOUSAND
20,000	TOO ZERO THOUSAND

Ordinarily time is stated in four digits, using the 24-hour clock. When no misunderstanding will occur, the last two digits may be used, as in a position report. When reporting an ETA or an ETE always use four digits. When reporting a position such as "Over the Dixie fan marker 1237," the pilot would say: "Position Dixie THU-REE SEVEN;" and ETA of 1345 is reported as "WUN THU-REE FOWER FI-YIV;" and ETE of 2 hours and 50 minutes is reported as "TWO HOURS AND FIVE ZERO MINUTES."

STANDARD PHRASEOLOGIES

It is inadvisable to lay down precise wording for all procedure phrases likely to be required in a pilot's radio work; however, the following are a few of the accepted and more commonly used expressions.

Term	Meaning
ROGER	Transmission received and understood. (Does not mean YES.)
OVER	Transmission ended, reply expected.
OUT	Transmission completed and no reply is expected. (Do not say AND OUT.)
WILCO	Will comply with your instructions.
WAIT	To wait for a short time, to expect an answer.
STAND BY	Guard this frequency.
SAY AGAIN	Repeat. (Use for any desired repetition.)
WORDS TWICE	Used when reception is difficult and it becomes necessary to have a message spoken more than once.
NEGATIVE	Used instead of NO.
AFFIRMATIVE	Used instead of YES.
INSTRUMENT FLIGHT RULES	Used instead of IFR.
VISUAL FLIGHT RULES	Used instead of VFR.

REPORTS

The correct sequence and information for giving position reports, changes in flight plans, clearance from non-military stations, and in-flight weather reports are listed in 08-15-1 and should be followed as closely as possible using the standard voice procedure.

Direction Finding

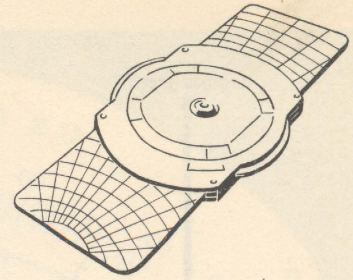
Direction finding (D F) procedures along with the proper voice procedures for D F are outlined in detail in 08-15-1.

Distress Procedures

When an aircraft is in distress and the pilot is unable to establish two-way radio communication on any frequency, he transmits as follows:

"Mayday-mayday-mayday. This is Air Force 1234. This is Air Force 1234. This is Air Force 1234. My approximate position is.........., Over."

The pilot may follow this emergency transmission with any other information he deems necessary. The mayday transmission serves as a notice or warning to other aircraft that someone is in distress. Although channel "D" (121.50 mc) has been designated as the aeronautical emergency frequence, the pilot in distress should use any frequency at his disposal. This procedure is outlined in T. O. 08-15-1 and additional information is also given in T. O. 08-15-2.



CHAPTER SIXTEEN

Use of the E-6B Computer

Dead reckoning is fundamental to all other methods of navigation, whether it be pilotage, radio, or celestial. Dead reckoning problems may be solved by rough estimates, mental calculations, arithmetical or graphic means, or by the use of a dead reckoning computer. Good piloting demands a quick, accurate, practical means of solving navigational problems; the aerial dead reckoning computer provides this means.

All computers are based on a slide rule (logarithmic scale) and a method for graphic solution of vector diagrams. A thorough knowledge of any one computer will greatly simplify transition to another. The ability to solve problems quickly and accurately on the computer is one of the most valuable techniques of the pilot-navigator.

DEFINITIONS

Dead reckoning — Determination of present distance and direction from a known previous position.

Calibrated air speed — The indicated air speed corrected for instrumental error.

True air speed — The calibrated air speed corrected for temperature and pressure.

Calibrated altitude — The indicated altitude corrected for instrumental errors.

Distance — Statute miles — 5,280 feet.

Nautical mile — one minute of latitude or 1.15 statute miles.

Kilometer — approximately $\frac{5}{8}$ statute mile.

True course — The direction of a line on a map or chart from departure to destination drawn on an azimuth from true north.

True heading — The true course corrected for wind; the direction the aircraft is pointed in relation to true north.

Track — The actual path of the aircraft relative to the ground.

SLIDE RULE FACE OF THE E-6B COMPUTER

The slide rule face of the E-6B computer is used for computing time-distance-speed problems; conversion of distance units; computing fuel consumption; and finding true air speed. The two scales are identically calibrated in logarithmic progression except that the inner scale has a convenient overlay calibration in "hours" so that time computations may be more easily accomplished.

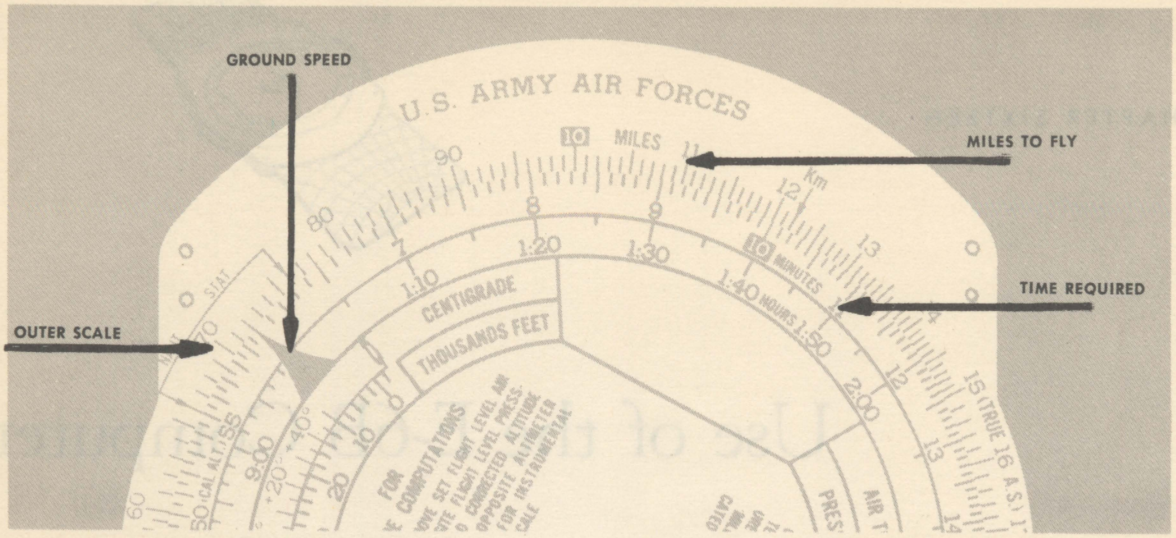


Figure 10.

The outer scale is normally called the mileage scale, but it will also be used to find true air speed, true altitude, and various units such as gallons, kilometers, nautical miles, proportional numbers, etc. The inner scale (the rotable disc) is called the time scale and is used principally as such; however, calibrated air speed, calibrated altitude, distance conversion indices, and numerical proportions are to be found on the inner scale.

The pilot should carefully study the graduations of the slide rule face and determine the variable values of each mark of calibration. Most errors common to this side of the computer result from inaccurate reading and faulty interpolation of the scales.

Time, Speed, Distance Problems

Most arithmetical calculations for time, speed, and distance needed in flight can be set up on the E-6B computer as proportions. If figures on the outer (miles) scale and inner (minutes) scale are considered as the upper and lower parts of a simple proportion, the pilot may substitute the known values into such proportion and then determine the unknown values of the problem. Figure 10 indicates the steps in proper sequence shown by the numbers 1-2.

If the ground speed and distance to fly are known, the time required to make the flight can be easily determined by considering the same proportion as in Figure 10:

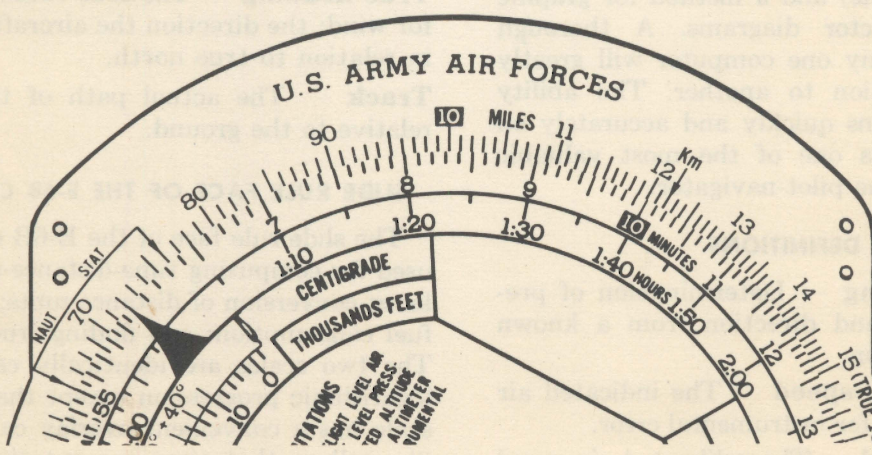


Figure 11.

1. Place the index arrow opposite the ground speed.

2. On the inner scale, opposite miles to fly, read the time required to make the flight.

If the ground speed and time flown are known, the distance flown is found by again using the same relationship as in the preceding problems:

1. Place the index arrow opposite the ground speed.

2. On the inner scale, opposite the time flown, read the distance flown.

Conversion of Distance Units

There are three conversion markers on the outer scale: nautical miles, statute miles, and kilometers. Place the unit given on the minute scale under the respective unit arrow on the miles scale. Read under the desired unit arrow the equivalent distance (Fig. 11).

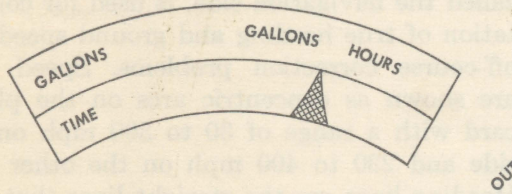


Figure 12.

Fuel Consumption Problems

Arithmetical calculations of fuel consumption for a flight can be set up on the E-6B as proportions. If the pilot will consider figures on the outer (miles) scale of the slide rule as comparable to the upper figures in proportion fractions and figures on the inner (minutes) scale as the lower figures of the proportion, he can readily substitute the known values into such a proportion and then solve for the unknown values using Fig. 12 as a guide.

To find the RATE of fuel consumption per hour, if the number of gallons used and the time flown are known, place the gallons used on the outer (miles) scale opposite the time flown on the inner (minutes) scale. Then, opposite the index arrow on the inner scale, read the *rate* of consumption on the outer scale.

To find the hours of fuel (cruising) left if the rate of consumption and the number of gallons remaining are known, place the rate of consumption on the outer scale opposite the index arrow on the inner scale. Then, opposite the gallons remaining, which is shown on the outer scale, read the hours and minutes of fuel remaining.

To find the quantity of fuel needed for a flight if the rate of consumption and the length of time required to make the flight are known, place the rate of consumption on the outer scale opposite the index arrow on the inner scale. Then on the inner scale opposite the time required to make the flight, read the quantity needed.

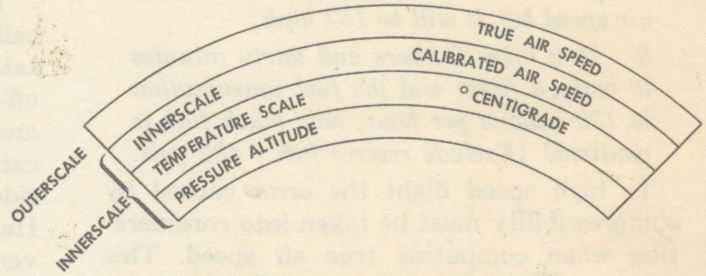


Figure 13.

Finding True Air Speed

True air speed is calibrated air speed corrected for temperature and pressure. If no calibrated air speed card is in the aircraft, indicated air speed will suffice in solving for true air speed. True air speed is used as a component part in solving for true heading and ground speed, and is found on the computer in the following manner:

1. Set the number 10 on the inner scale opposite the number 10 on the outer scale. The computer is now aligned to solve for true air speed.

2. Set the flight-level free-air temperature on the scale directly above the window.

CAUTION

Be sure to use the window marked "For Air Speed Corrections."

3. Opposite the indicated (use calibrated air speed if it is known) air speed on the inner scale, read the true air speed on the outer scale. Use Fig. 13 as a guide.

Practice Problems:

1. If at 10,000 feet pressure altitude with a free-air temperature of –5° C. and indicating 190 mph, the true air speed is 222 mph.

2. On a proposed cross-country flight at 8,000 feet the adiabatic chart gives the temperature at that altitude as 0° C. If indicated air speed is to be 165 mph, what will the true air speed be? It will be 187 mph.

3. If it takes 2 hours and thirty minutes to make a flight and the fuel consumption is 170 gallons per hour, how much fuel is required? (Exclude reserve fuel.) 425 gals.

In high speed flight the error caused by compressibility must be taken into consideration when computing true air speed. This compressibility error is so small at low air speeds and altitudes that it is neglected in practice.

The compressibility correction, obtained from the Compressibility Correction Table in Pilots Operating Instructions, is subtracted from the calibrated air speed and the resulting air speed, (Equivalent Air Speed) is substituted for calibrated air speed in the computation of true air speed.

ALTITUDE CORRECTIONS

The correction of altitude for temperature other than standard is approximate at best. Temperature conversions and lapse rates other than standard detract from the accuracy of the altitude corrections. Fair accuracy is obtained when the observed temperature at altitude is set opposite the observed pressure altitude in the correction window; true altitude is then read on the outer disk over calibrated altitude on the inner disk. CAUTION: Be sure this is set up on the scale marked—(FOR ALTITUDE COMPUTATIONS).

THE WIND FACE

The wind face of the computer, sometimes called the navigation side, is used for computation of true heading and ground speed and off-course correction problems. Speed lines are shown as concentric arcs on the plastic card with a range of 30 to 300 mph on one side and 230 to 400 mph on the other side. Heading lines are the straight lines that converge at a point below the plastic card and they indicate wind correction right or left from the true course line at the center. The graphic section at the lower end of the card is for the solution of off-course correction problems. Superimposed on the card is a rotable compass rose, opposite which is a drift scale with an arrow marked true index.

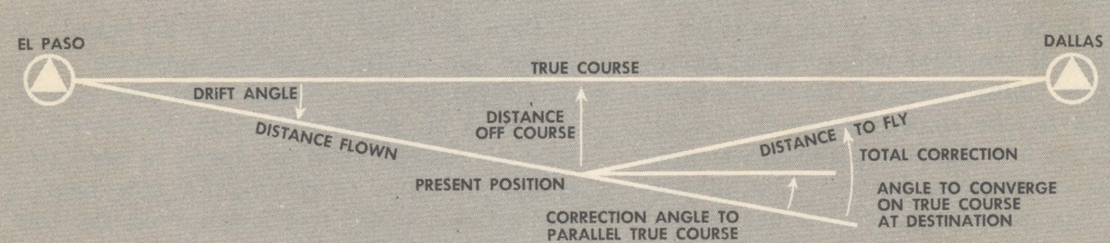


Figure 14

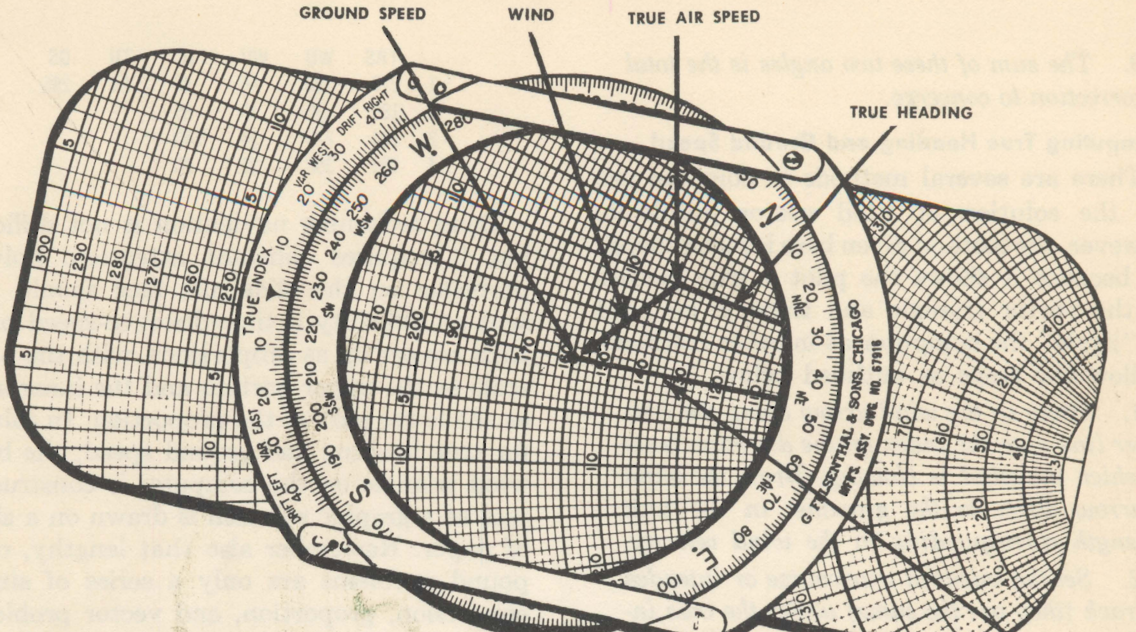


Figure 15. Solution to wind problem.

Off-Course Correction

The pilot can graphically determine how many degrees he has drifted from his intended true course or track by using the wind face of the computer; then, after determining the drift, he can employ a correction that will cause him to parallel his intended track. He can next make another correction in his heading that will cause his flight path to converge on the destination or some selected point along the intended track.

From the grommet, draw a line along the center line of the slide equal in length to the mileage off course. Then rotate the azimuth scale 90° so that the line drawn for distance off-course projects at right angles to the center line of the slide. If off course to the right, the line should lie to the right. Adjust the slide so that the mileage flown along the true course appears under the grommet. Now visualize the triangle so indicated in Figure 14 shown. There should appear on the computer the same triangle as is shown in Figure 14 with the center line the intended track and the drift line that passes through the outer end of the off-course line the actual track made good. Therefore, the angle between these two lines is the drift angle and is roughly equal to the drift correction. A correction of this amount will parallel the intended track. In order to find the extra correction to converge at the destination, readjust the slide until the distance remaining to the destination lies under the grommet. The new angle that is formed is the extra correction and is added to the first angle to obtain the total course correction for convergence.

Another method may be utilized in solving the off-course problem which involves the slide-rule face. This method is quicker but since the solution is not graphic, the pilot must take greater care in setting it up on the computer because of the increased likelihood of error. An angle formed by an off-course triangle where the distance traveled is 60 miles and the off-course distance is one mile is 1°. Using this known proportion, the pilot can set up the problem to solve for the correction angle as follows:

1. *Set the distance off course over the distance flown. Read the angle of drift over the index arrow of the inner scale. This angle will only parallel the intended track; so the second portion of the problem must be computed in the same manner.*
2. *Set the distance off course over the remaining distance to the destination and read the angle over the index.*

3. *The sum of these two angles is the total correction to converge.*

Computing True Heading and Ground Speed

There are several methods in common use for the solution of wind vector problems; however, the method given here is recommended because it shows the pilot a true picture of the vector triangle and there is no need to "jiggle" the computer as in other methods. Follow the steps as outlined below:

1. *Draw in the wind arrow along the center line with the index on the direction from which the wind is blowing. Draw the wind arrow down to the grommet in the unit length corresponding to the wind velocity.*

2. *Set the intended true course or intended track (they are the same) under the true index.*

3. *Adjust the slide so that the true air speed (TAS) appears under the tail of the wind arrow.*

4. *Read the ground speed under the grommet.*

The basic wind triangle is now drawn on the computer. The angular difference between the center line (TC) and the drift line (TH) that appears at the tail of the wind arrow is the amount of correction or "crab" needed to offset the wind. Apply this correction to the true course to determine the true heading. If the tail of the wind arrow lies to the right of the intended (center line), the true heading is to the right of the true course and the correction is added to the track. The correction is subtracted from the true course if the tail of the wind arrow lies to the left.

Listed below are some typical wind problems:

	TAS	WD	WV	TC	TH	GS
1.	270	180	40	48	54	295
2.	180	90	18	65		
3.	224	220	34	340		
4.	280	350	22	75		

Dead reckoning navigation is not difficult, but it requires constant attention. Solving problems on the slide'rule face should present no difficulty if time-distance-speed problems are set up as proportions, with the outer scale as the upper portion and the inner scale as the lower part of the proportion. In solving for true heading and ground speed, the basic wind triangle on the computer is constructed just as a graphic solution is drawn on a sheet of paper. Remember also that lengthy, compound problems are only a series of simple conversion, proportion, and vector problems. A few practical problems are shown below:

1. The true course between two cities 720 nautical miles apart is 335°. By burning fuel at the rate of 185 gal. per hour and indicating 240 mph at 10,000 feet with a free-air temperature of 5° C, how much fuel will be used on the trip if the wind is from 37° at 53 mph?

2. After flying a distance of 140 miles, a pilot finds that he is off-course to the right 12 miles. If he has 220 miles to go to the destination, how many degrees must he correct in order to converge on course at the destination?

3. A pilot holds 92° magnetic heading to maintain course along a radio range beam whose published heading is 87°. The variation in the area of his flight is 18° east. His indicated air speed is 210 mph at 9,000 feet where the temperature is 0°. If his last known ground speed was 219 mph, what is the direction and velocity of the wind?

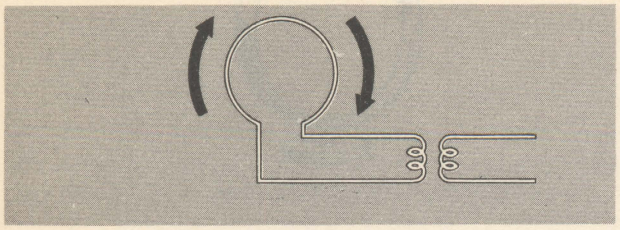


Figure 16.

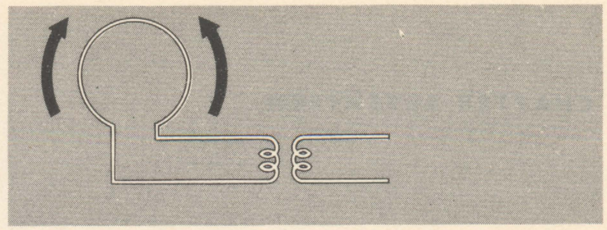


Figure 17.

voltages, being equal and opposite, cancel each other. Therefore, no current flows in the primary of the loop transformer, and there is no input to the receiver. As the loop is turned from this position (Figure 19) one side is brought closer to the transmitter than the other, and there is a slight delay between the time the radio wave hits one side and the time it hits the other. Consequently, there is a phase difference between the voltages induced in each half of the loop. There is a resultant current through the transformer and some input to the receiver.

As the rotation of the loop is continued (Figure 20), the one side continues to come closer to the station, and the other side continues to move farther away until the plane of the loop is in line and the other is as far away. The time lag and phase difference between them is at a maximum, the resultant (difference) voltage is at a maximum and the input to the receiver is at a maximum.

As the loop is rotated beyond the position where the plane of the loop is in line with the station (Figure 21) the difference in station-to-loop distance between one side of the loop

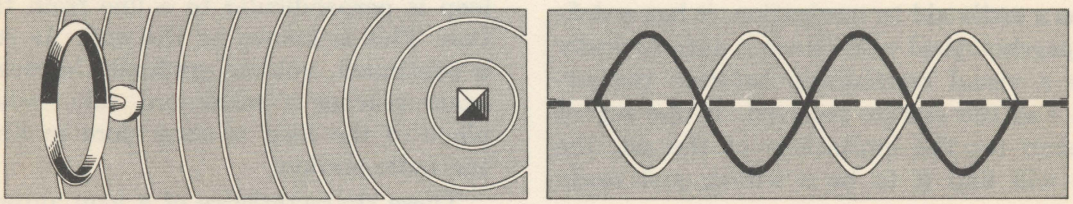


Figure 18.

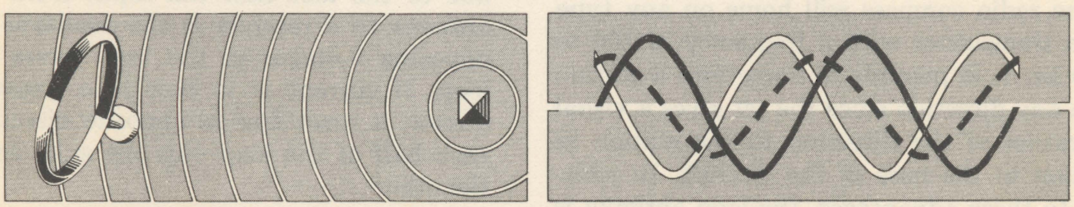


Figure 19.

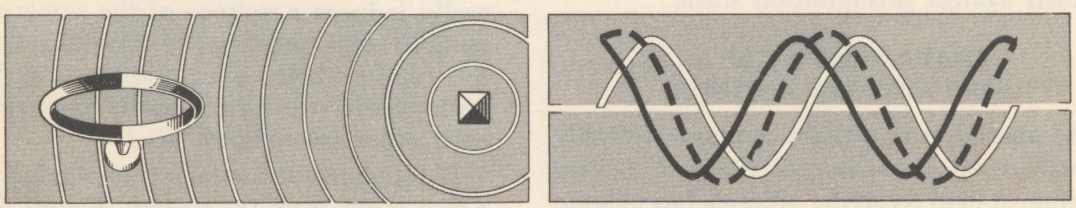
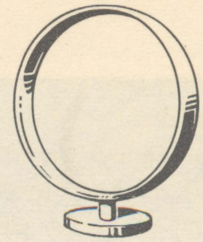


Figure 20

CHAPTER SEVENTEEN



Radio Compass Equipment

The radio compass is a valuable aid to navigation. The automatic feature of the compass makes its use much easier for the pilot and greatly increases its utility. In addition to its use as a radio aid to navigation, it has a definite psychological value since it automatically gives a visual relationship between the aircraft and the station received. If due regard is taken for the limitations of the set, the pilot will find it to be a willing and ready servant.

The radio compass will home on any type radio transmitter with a frequency of 100 to 1750 kc. It is possible to home into a station from any direction since the set gives a visual indication of the direction to the station in relation to the nose of the aircraft. In addition to these advantages, the loop antenna is shielded against precipitation static.

CHARACTERISTICS OF A LOOP RECEIVING ANTENNA

The operation of a radio compass is chiefly dependent on the characteristics of a loop antenna. A loop receiving antenna has characteristics similar to those of a loop transmitting antenna.

A loop receiving antenna, (Figure 16) supported vertically, gives maximum reception when the plane of the loop is in line with the transmitting station. As the loop is rotated from this position, volume gradually decreases, reaching a minimum when the plane of the loop is perpendicular to a line from the station. This is known as the null. As rotation is continued, volume gradually increases and again reaches a maximum value when the plane of the loop is once more in line with the radio station.

These characteristics of a loop antenna are due to the fact that the input from a loop antenna to a receiver is the resultant of the opposing voltages in the two halves of the loop. If current is to flow in a looped conductor, it must flow in opposite directions in each half of the loop—up one side, down on the other.

A radio wave striking a loop, however, generally induces a voltage of the same polarity on both sides, pushing the current in the same direction on both sides, and causing the currents of the two halves of the loop to oppose each other (see Figure 17).

If the plane of the loop is at right angles to a line drawn from the station (Figure 18) both sides are equidistant from the station. The radio wave hits both sides of the loop at the same point in its cycle, and the same voltage is induced in each half of the loop. The two

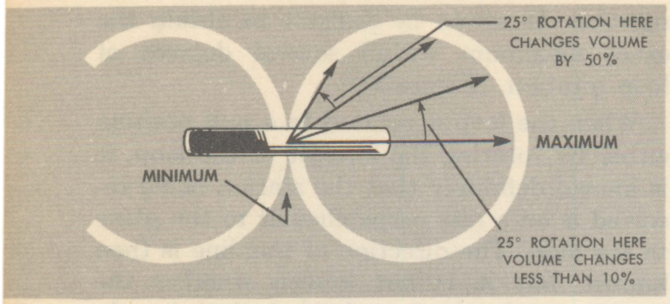


Figure 24.

ment for the Air Force. It can be used for position plotting, homing, and aural reception.

AUTOMATICALLY ROTATED LOOPS

In the radio compass there is a mechanism which automatically rotates the loop to a null position. This mechanism controls the loop by means of a motor which rotates the loop to the right if current flows through it in one direction, and to the left if current flows through it in the opposite direction. The direction in which the current flows through the motor, and whether it flows at all, depends upon the action of two thyratron loop-control tubes. (A thyratron is a grid-controlled rectifier.) If neither of the thyratrons allow current to flow, the motor does not rotate the loop. If one thyratron (call it thyratron No. 1) allows current to flow, the direction of flow is such that it causes the motor to rotate the loop to the right. If the other thyratron (thyratron No. 2) allows current to flow, the direction of flow is such that it causes the motor to rotate the loop to the left.

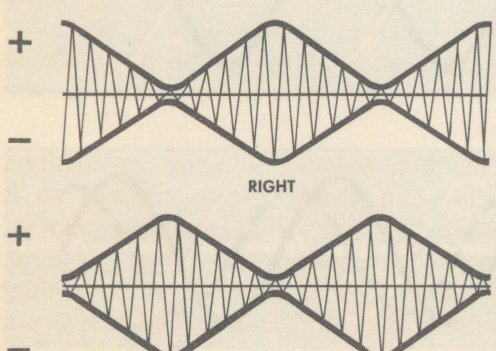


Figure 25.

Before current can flow through a thyratron, both its plate and grid must be positive. The plate voltage of the thyratrons is controlled by an audio oscillator which alternately makes the plates positive or negative. This audio oscillator voltage also modulates the incoming loop signal at exactly the same rate as it switches the voltage on the plates of the thyratrons. (Figure 25).

The loop voltage for a station on the right of the loop is 180° out of phase with the loop voltage for a station to the left. The loop voltage adds to the voltage of the non-directional antenna or subtracts from it, depending on the direction of the station. Consequently, when the voltage of the non-directional antenna and the modulated voltage from the loop are combined, the modulation envelope for stations on the right of the loop is 180° out of phase with the modulation envelope for stations to the left of the loop.

This modulation envelope, after amplification and detection, is connected in push-pull to the grids of the thyratron tubes, so that when the grid of one thyratron is positive the grid of the other thyratron is negative.

The result of this arrangement is as follows: The plates of the thyratrons vary with the audio voltage. Both plates are positive or both plates are negative at the same time.

The grids of the thyratron vary with the modulation envelope, but are connected push-pull, so that when one is positive, the other is negative. (Figure 26).

If the station is to the right of the null on the loop, the grid in thyratron No. 1 is positive when the plate is positive, and the tube conducts current, causing the motor to rotate to the right. In thyratron No. 2, when the grid is positive, the plate is negative; and when the plate is positive, the grid is negative. It does not conduct current and has no effect on the motor.

If the station is to the left of the loop, the grid voltages are 180° out of phase with what they were when the station was to the right. In thyratron No. 1, when the grid is positive, the plate is negative; and when the plate is positive, the grid is negative. This thyratron

and the other decreases, the phase difference decreases, and the input into the receiver decreases. As the loop is rotated past the null point (Fig. 18 and 22) the phase of the resultant voltage shifts by 180° because the direction of the current flow is reversed. When the left side of the loop is closer to the station (Fig. 19 and 23) the current in the loop flows in one direction. When the right side is closer, it flows in the opposite direction.

USE OF THE NULL POSITION

It is very difficult to determine at exactly which position of the loop a signal received is at a maximum. The exact position of the loop that gives a minimum signal is much easier to determine. Consequently, in using the loop antenna for direction finding, the point of minimum reception (null) is sought instead of the point of maximum reception. With a well-designed loop antenna, the exact minimum can be obtained within ½° of loop rotation. It would be difficult to obtain the exact maximum within several degrees of loop rotation. (Figure 24).

When the loop is rotated to a null position either by rotating the aircraft or the loop, it is known definitely that the station being received is on a line perpendicular to the plane to the loop. The direction of this line is then known, but it is not known whether the station is ahead of or behind the aircraft. This is known as the 180° ambiguity.

AUTOMATIC RADIO COMPASS

The automatic radio compass equipment includes a loop, a non-directional antenna, a radio receiver, and a 360° scale to indicate the position of the loop with reference to the longitudinal axis of the aircraft. It has, in addition, a loop motor mechanism for rotating the loop, and loop control circuits for automatically controlling the loop motor mechanism. At present this is standard equip-

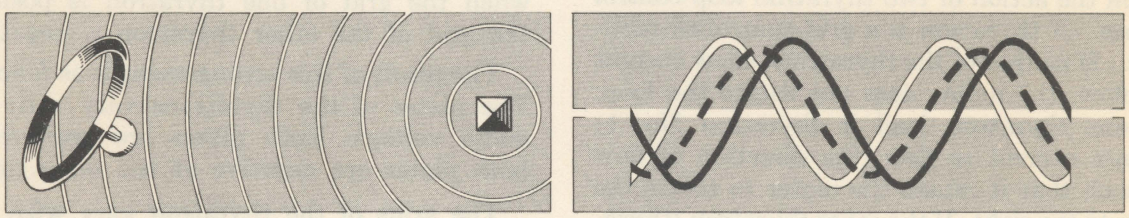


Figure 21.

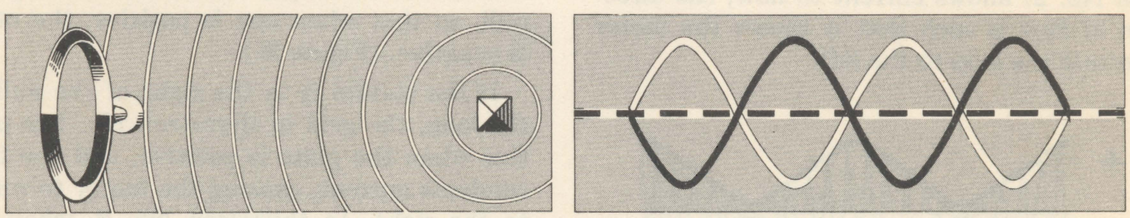


Figure 22.

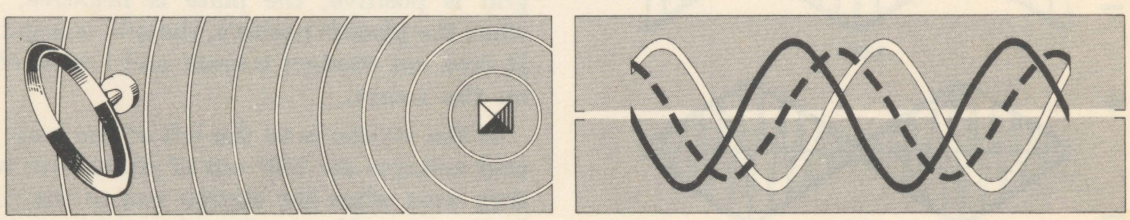


Figure 23.

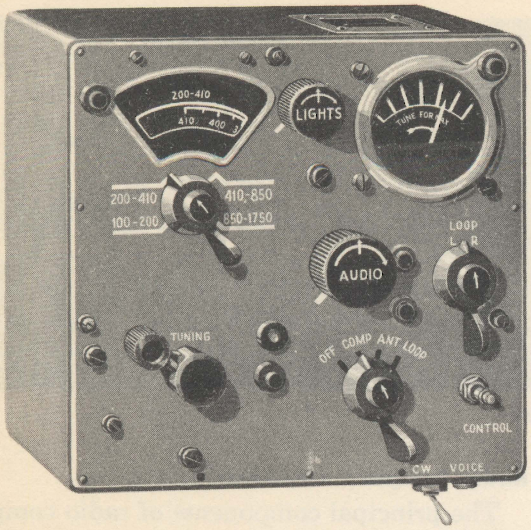


Figure 27—AN ARN-7, Control box.

pass through the dehydrator where it loses its moisture as a result of the absorptive action of the silica gel. The cobalt chloride serves as an indicator of the moisture content of the silica gel, changing from dark blue to light blue or pink as the dehydrator loses its effectiveness. In the base of the loop housing are a loop motor, an autosyn transmitter, and a compensator.

The loop motor is a small two-phase induction motor which rotates the loop through a gear train and shaft. The motor has two windings, a low-impedance winding and a high-impedance winding. The low-impedance winding is continuously supplied with 400-cycle current. When the high-impedance winding is supplied with current of 90° out of phase with the current in the low-impedance winding, the armature rotates. The direction of its rotation depends upon whether the current in the high-impedance winding is 90° ahead of the current in the low-impedance winding or 90° behind it.

The autosyn transmitter electrically transmits the angular position of the loop to one or two autosyn indicators (receivers) causing the pointer on each indicator to rotate as the loop does, so that the exact position of the loop can be read at either of the indicators.

The autosyn transmitter and the autosyn receivers closely resemble each other physically, electrically, and magnetically. Each consists of a rotor winding and three stator windings. The three stator windings are 120° apart electrically. The rotor winding of the transmitter is in parallel with the rotor winding of the receiver, and the stator windings of the transmitter are in parallel with those of the receiver. Alternating current flows through the rotor windings and induces voltages in each of the stator windings proportional to its position with reference to the rotor winding. The rotor of the receiver is free to rotate, but the rotor of the transmitter is connected to the loop. When the loop rotates, it causes the rotor of the transmitter to rotate. This changes the voltages induced in the transmitter stator windings. Because the receiver windings are in parallel with the transmitter windings, the same change occurs in the receiver windings. The magnetic field at the receiver changes accordingly and causes the rotor in the receiver to line up in the same position as the rotor in the transmitter. Since the rotor in the transmitter is connected to the loop and the rotor in the receiver is connected to the indicator pointer, the indicator pointer is rotated to the same angular position as the loop.

Interference by wings, engines, and other parts of the aircraft may cause distortion of the radio waves striking the loop and keep the loop from lining up properly with the station. The error caused by these factors is

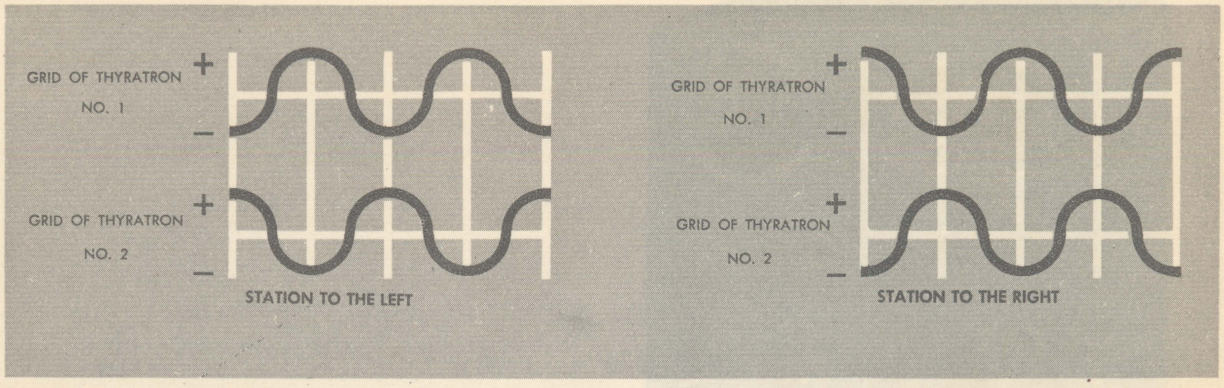


Figure 26.

does not conduct current, therefore, and has no effect on the motor. In thyratron No. 2, when the grid is positive, the plate is positive; and the tube conducts current causing the motor to rotate the loop to the left.

If the loop is at the null, there is no loop voltage to be modulated, and neither of the thyratron grids is positive. Neither tube will conduct, and the loop will not be rotated.

It might seem, at first, that this leaves the 180° ambiguity unsolved, for there are still two null positions, one in front of the loop, and the other behind. Actually, however, the 180° ambiguity is avoided because the false null position is not stable. If the loop is on the false null and happens to be jarred or turned slightly to the right, the action of the loop motor mechanism will continue to turn it to the right until it reaches the true null position. If the loop is jarred or turned slightly to the left of the false null, the action of the loop motor mechanism will continue to turn it to the left until it reaches the true null. Since there is always some slight jarring, the loop never rests on the fulse null.

AIR FORCE RADIO COMPASS EQUIPMENT

There are two standard radio compass sets in use in the Air Force, the AN/ARN-7 and the AN/ARN-6. An older model set, the SCR-269, which is in limited use, resembles the ARN-7 in most respects. The ARN-6 is the newest design, and though it is similar to the ARN-7 in principle and employment, it is a much lighter, smaller, and improved equipment.

Radio Compass AN/ARN-7

The principal components of radio compass ARN-7 are the receiver, nondirectional antenna, directional antenna (loop) assembly, two indicators, two control boxes, and an inverter.

Antenna assemblies. The nondirectional antenna may be one of several types. The exact length of this antenna does not matter, but the greater the proportion of its vertical length to its horizontal length, the better it will be. Vertical antennas, supported by stub-masts, are satisfactory. The antenna and its lead-in should be at least 3 feet away from the loop.

The loop antenna of the ARN-7 is an 8-turn coil with a center tap that is grounded. It is electrostatically shielded by an aluminum shield split at the top, and is housed in a plastic tear-drop housing. The loop assembly is installed on either the top or belly of the aircraft, generally on the fore-and-aft center line of the fuselage, as far away as practicable from sources of interference in the aircraft. The loop is mounted on a rotatable shaft which is driven by a motor through a gear train.

The loop housing is made as airtight as possible and sealed to the aircraft to keep the interior free from moisture. Some air passage is necessary, however, to equalize pressure at various altitudes. This is afforded through a dehydrator unit, which is a plastic tube filled with an 8-inch column of silica gel impregnated with cobalt chloride. All air entering or leaving the loop assembly must

The LOOP L-R switch operates only when the function switch is on LOOP. It causes the loop to be rotated in a counterclockwise or clockwise direction, depending on whether the switch is turned to the left or right. Two speeds of rotation are possible in either direction. Merely turning the switch to the left or right causes the loop to rotate at a slow speed. Turning the switch and at the same time pressing the button in the center of the switch causes

*Figure 29—
Indicator I-81.*

the loop to rotate rapidly. When the button is pressed, the resistor in the circuit is shorted out, and more current is allowed to flow through the motor. The LOOP L-R switch has to be held in the position desired for it springs back to the inoperative position when it is released.

The AUDIO control knob controls variable resistors. On COMP position, it varies a resistor in the headset circuit which controls the level of the audio signal in the headset, but it does not affect the sensitivity of the receiver. On ANT and LOOP positions of the function switch, it varies a resistor in the cathode circuit of the first and second RF amplifiers and first detector. This resistor determines the level of the audio signal by controlling the sensitivity of the receiver. Where two control boxes are used, it is possible to vary the volume at the box not in control only if its function switch is on COMP or OFF position.

Two spare instrument lamps are mounted on the control box. Between them appears the word "SPARES."

The LIGHTS control regulates the brilliance of the instrument lamps on the control box.

The ARN-7 equipment has a CW-voice switch located on the control box, whereas the SCR-269 equipment has this switch on the receiver.

INDICATORS. Two types of indicators are used with the ARN-7. They are both driven by an autosyn receiver mechanism almost exactly the same as the autosyn transmitter

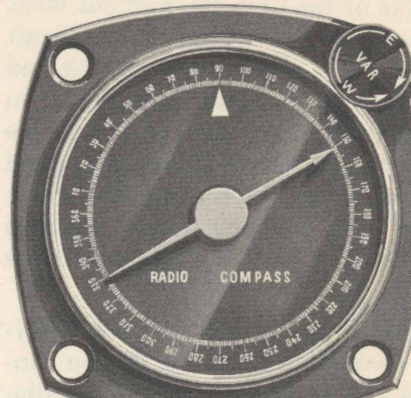


*Figure 30—
Indicator I-82.*

mechanism at the loop. Both indicators show the angular position of the loop with reference to the longitudinal axis of the aircraft.

Indicator I-81, known as the pilot's indicator, is generally installed on the pilot's instrument panel. The scale divisions on this indicator each represent 5°. The zero is omitted in all the number indications. Thus, 30° is indicated by 3, 60° is indicated by 6, and so on. The line marked 0, like the lubber line on a magnetic compass, indicates the longitudinal axis of the aircraft. (Fig. 29).

Indicator I-82, known as the navigator's indicator, is generally installed in the navigator's or radio operator's position. The scale divisions of this indicator each represent 1°. The scale may be rotated by turning the knob marked VAR. On this indicator, the triangular index is in line with the longitudinal axis of the aircraft and represents the nose of the aircraft. (Fig. 30).

POWER SUPPLY. Radio compas AN ARN-7 requires both a DC and an AC power supply. The DC power is used for the operation of the control relays and band-switching motor,

known as "quadrantal error" (radio compass deviation). Correction for quadrantal error is applied through the compensator unit which couples the loop shaft to the autosyn motor. The compensator does not turn the autosyn motor to the exact position of the loop but to a corrected position. The corrected position is then transmitted to the indicators.

The compensator unit consists of a cam assembly adjusted by screws spaced 15° apart around the edge of the unit. To find out what corrections need to be made, the aircraft flies a pattern with reference to a selected station. Readings on the indicator are taken at various headings, and the deviations are plotted. Correction for the deviation is applied every 15° by means of the screws. The exact procedure for compensating radio compass AN/ARN-7 can be found in Technical Order AN 08-30 ARN 7-2.

CONTROL BOXES. Radio compass AN/ARN-7 is remotely controlled from one or two control boxes, depending on the type of installation. In the lower right hand corner of each control box is a control switch. When pressed, this switch operates a relay which transfers control from one box to another. A green light is lit on the box which is in control (Fig. 27).

A band-selector switch on each box controls a band change motor which switches in the tuned circuits for the desired band. The band-selector switch also operates a mask over the dial which covers all parts of the dial except the frequency indications for the band selected. Radio compass AN/ARN-7 has a 4-position band selector switch with the following bands: 100-200 kc., 200-410 kc., 410-850 kc., and 850-1750 kc. The SCR-269 has a 3-position switch with the latter three positions.

A tuning crank turns the ganged tuning condensers in the radio compass unit by means of a train of gears and a flexible tuning shaft. It also turns the dial.

A tuning meter helps make tuning accurate. Maximum deflection of the pointer to the right indicates best receiver tuning. (Fig. 28.)

A four-position function switch controls the manner in which the compass operates. On the OFF position, the compass is inoperative. On COMP position, both the sensing and loop antennas, and all the loop control circuits are used. In this position, the loop is automatically rotated to face the station to which the receiver is tuned.

The indicator shows the direction in which the loop faces. On ANT position, only the nondirectional antenna is in the circuit, and the radio compass is used as any other communications receiver. On LOOP position, only the loop antenna is used. When the switch is on LOOP, the position of the loop antenna is shown on the indicator, but the loop is not rotated automatically. On this position, equipment is used as a compass with a manually-controlled loop.

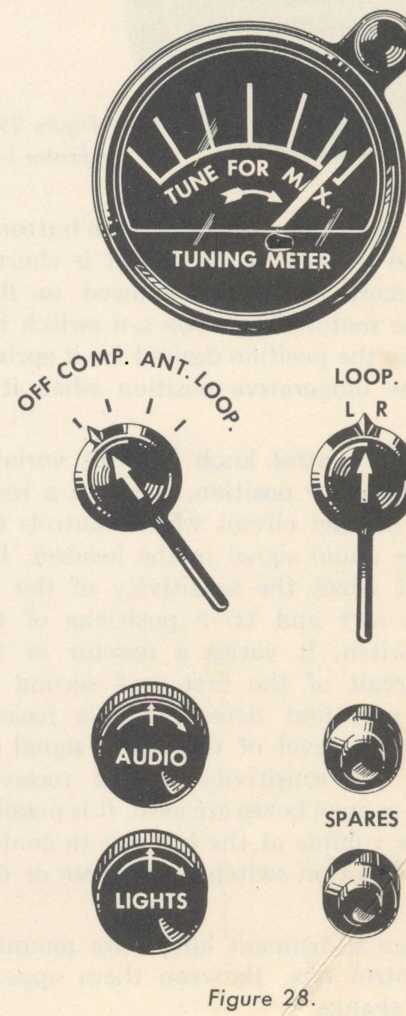


Figure 28.

by two methods. On COMP position, the CW signal is modulated by a 900-cycle note supplied by a tone oscillator. On ANT and LOOP positions, the CW signals are made audible by a beat-frequency oscillator. Differences also exist in the audio output stages, the sensitivity circuits, and the control switching relay.

Antennas

Like the ARN-7, the ARN-6 uses nondirectional antennas of several types. These may be belly or top mounted but must be at least 3 feet from the loop antenna.

The loop antenna of the ARN-6 consists of an iron core loop of 9 turns, center-tapped to ground by a shunt coil of 12 turns. The loop is electrostatically shielded and is located in a hermetically sealed glass dome filled with dry nitrogen. The loop is rotated by a drive motor through a reducing gear train. The entire loop unit is placed in a housing and may be located either on the top or bottom of the aircraft.

At the top of the glass dome container surrounding the loop is a moisture indicator. It contains specially treated litmus paper which indicates the moisture content of the air within the glass dome container. If the moisture indicator is dark blue, the air in the dome is dry. If the moisture indicator is light blue or pink, moisture has leaked into the loop assembly, and the assembly must be replaced.

In the base of the loop unit are a loop motor, a compensator, and an autosyn transmitter. The loop drive motor is very similar to the two-phase induction motor used in the ARN-7. It uses a shaft and reducing gear arrangement to rotate the loop. Electrically, the motor circuit consists of a low-impedance winding, which is constantly energized by the 100-cycle AC from the vibrator inverter, and a high-impedance winding through which current flows when one or the other of the two loop control tubes fires. The phase of the current through the high-impedance winding (and the direction in which the motor turns) is determined by the operation of one of the loop control tubes. This is determined, in turn, by the angle of the loop with respect to the station being received.

The autosyn system in the ARN-6 consists of an autosyn transmitter and two autosyn receivers, one in each of the indicators. The electrical and functional operation of this remote indicating device is essentially the same as the autosyn system in the ARN-7.

The compensator unit, to correct for quadrantal error, is in the base of the loop unit. It is essentially the same mechanically and electrically as the compensator in the ARN-7. Procedures for correcting for quadrantal error (compass deviation) are available in the technical order, but only trained personnel should attempt these corrections.

CONTROL BOX. Radio compass ARN-6 may be remotely controlled from one of two remote control boxes. In some installations, as in fighter aircraft, only one control box is used.

Differences between the ARN-7 and ARN-6 audio controls are more electrical than functional. On ANT and LOOP positions, the ARN-6 audio control functions in exactly the same way as in the ARN-7. On this position, it is a gain control, that is, a variable resistor in series with the cathodes of the first detector and first and second RF amplifiers. On COMP position, the audio control is a volume control in both the ARN-6 and ARN-7 with the only difference that in the ARN-7 it is a single variable resistor while in the ARN-6 it is an attenuator bridge. The tuning dial alignment is identical to that of the ARN-7. The control button is located in the center of the band change switch, and control of equipment is indicated by the functioning of the dial lights.

The degree to which the LOOP L-R switch is turned to the left or right controls the speed of rotation of the loop.

INDICATORS. Two indicators are used with the ARN-6 radio compass. The pilot's indicator has an adjustable scale and has calibration markings. The navigator's indicator is identical to the I-82. A pilot's night indicator with the pointer and numerals covered with luminescent material is also available for AN ARN-6 installations.

and is supplied directly by the central power system of the aircraft (C. P. S.) The 400-cycle, 115-volt, AC power used for the receiver, loop motor, and autosyn transmitter is supplied by an inverter unit.

An inverter is a DC motor and an AC generator combined in one machine. The inverter obtains DC power from the C. P. S. and converts it into 400-cycle, 115-volt, AC power. In most aircraft, the inverter is turned on by a separate switch, but in some it is turned on by the function switch of the radio compass.

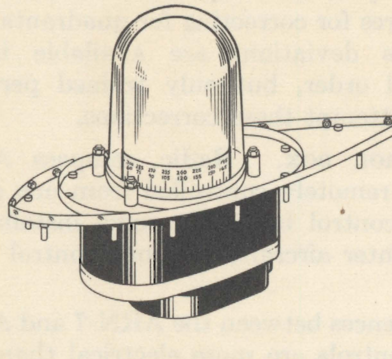


Figure 31—ARN-6 Loop antenna.

The radio compass is protected by two fuses, both located on the terminal board of relay BK-22. The AC circuit is protected by a 3-ampere fuse, and the DC circuit by a 5-ampere fuse. If the inverter is switched on from the compass control box, the DC circuit on the radio compass requires a 20-ampere fuse to permit the flow of the additional current through it.

ADJUSTMENT—TUNING DIAL ALIGNMENT. To make sure that the tuning dials on the control boxes are aligned with the tuning condenser, proceed as follows:

1. *Turn the band switch to the band of the highest frequency (850-1750 kc).*
2. *Turn the dial toward the low end of the band until a stop is reached.*
3. *If the ALIGN mark is not directly under the reference line, the dial reading on that control box is incorrect.*
4. *To correct the dial reading, disconnect the tuning shaft at the control box, rotate the dial until the ALIGN mark is under the reference line, and reconnect the tuning shaft.*
5. *Recheck the alignment.*
6. *Repeat the alignment procedure on the other control box.*

Radio Compass AN/ARN-6

Radio compass AN/ARN-6 operates on a frequency range of 100-1750 kc, divided into four bands, and performs the same functions as the larger models. It differs from the ARN-7 in several respects. It does not use an inverter to supply AC to a high voltage rectifier or to the automatic circuits. Instead, a vibrator unit built into the receiver unit provides alternating current for automatic operation. Plate and screen voltages are obtained directly from the DC source. The external type dehydrator unit used in the ARN-7 is replaced by a moisture indicator which is located in a glass dome surrounding the loop antenna.

Circuit changes are more electrical than functional. The ARN-6 uses 16 tubes rather than 15. It has no audio oscillator to modulate the loop signal—the vibrator supplies 100-cycle AC for this purpose. A special tuning indicator tube is used to indicate resonance in the RF stages of the receiver and control the tuning indicator needles on the control boxes. Reception of CW signals is accomplished

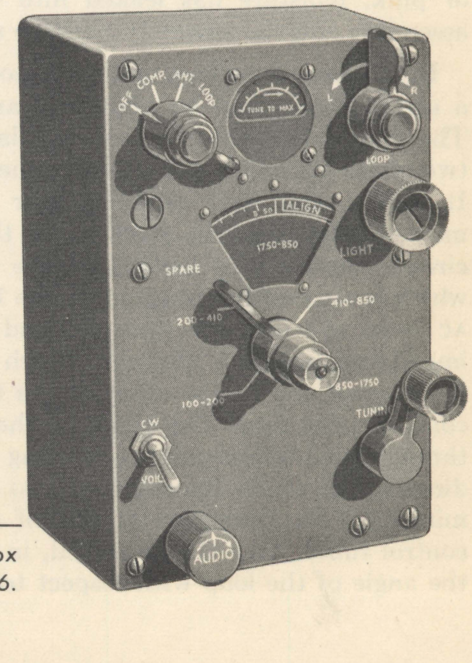


Figure 32—Control box AN ARN-6.

The next advancement was the construction of a radio set with a manually rotatable loop. The loop antenna was rotated by the pilot or navigator by means of a small crank situated near the azimuth indicator. This azimuth scale was calibrated in degrees and, by means of a pointer, always indicated the position of the plane of the loop in relation to the longitudinal axis of the aircraft. This type of antenna made possible the taking of bearings and tracking.

The latest development we have today is the automatic loop antenna. By the addition of a sensing antenna, the plane of the loop automatically lines up with the station tuned in and indicates its relative bearing from the aircraft by means of a pointer on an azimuth scale. Two advantages are:

1. This set eliminates the 180° ambiguity.

2. Once the station is tuned in, it eliminates any mechanical adjustment by the pilot.

OPERATION OF THE AUTOMATIC RADIO COMPASS

The proper operation of the automatic radio compass set requires an understanding of the switches and how to interpret the various indicators. These are:

1. The *function, or antenna selector switch* serves as an on-off switch and selects the type of operation. It has four positions:

   OFF.

   COMP In this position, two antennas are being used the loop and the sensing. It is only in this position that the automatic features of the set are functioning.

   ANT In this position only the sensing antenna is functioning, giving the same reception as the range receiver.

   LOOP In this position only the loop antenna is functioning. This position is used for emergency "null" procedure or, in case of extreme static, for best reception.

2. The "*control button*" is used to transfer control of the set from one unit to the other.

The "*green light*" indicates which unit has control, that is, the unit with the green light on has control of the set.

The "*band change*" switch is used to select the desired band of which there are four available. They are:

100 to 200 kc (This band is not available on the SCN-269)
200 to 410 kc.
410 to 850 kc.
850 to 1750 kc.

The tuning crank rotates the chosen band to the desired frequency.

The "*maximum*" indicator indicates the intensity of the carrier wave reception.

The "*left-right*" switch rotates the loop by means of a small motor when the set is on "LOOP" position.

The "*voice-CW*" switch, when set on "CW," modulates the carrier wave giving it a steady, audible hum.

The *pilot's azimuth indicator* indicates the position of the loop antenna in relation to the longitudinal axis of the aircraft.

TYPES OF STATIONS

The following are some of the types of stations possible to receive on the automatic radio compass set.

Ranges Loop and Adcock.
Homing, or nondirectional radio beacons.
Standard broadcast.
Control towers (from 200 to 400 kc).
Aircraft liaison transmitters operating in the 200 kc to 600 kc range.

FACTORS TO CONSIDER IN SELECTING A STATION

The factors to consider in selecting a station are:

1. The proximity of the station to the field.

2. The power of the station. In case of range stations this can be found by referring to Radio Facility Charts, (T. O. 08-15-1).

For the power of broadcast stations refer to the Radio Data and Flight Information book, (T. O. 08-15-2).

3. The type of station. Choose one that transmits a constant carrier wave. Choose Adcock-type ranges over loop-type whenever possible because the strongest radiation from the Adcock range, that from the center tower, is nondirectional.

STEPS FOLLOWED IN TUNING IN THE SELECTED STATION

The steps to follow in tuning in the selected station are:

1. Place the function switch on "ANT" position.

a. This avoids the possibility of the loop being on a "NULL" position.

b. This also avoids the damage caused by the loop homing on various stations as the selected station is tuned in.

2. Press the control button to gain control of the equipment in case the control is in the other unit as indicated by the green light.

3. Select the desired frequency band.

4. Turn the tuning crank to get the desired frequency on the band chosen.

5. If the automatic features of the set are going to be used, tune to maximum carrier wave reception as indicated by the "maximum" indicator.

6. If the loop is being used, tune for either maximum carrier wave or maximum sound reception. If using the "CW" switch, tune for maximum carrier wave reception.

AUTOMATIC DIRECTION FINDING (ADF) METHODS AND PROCEDURES

Orientation with the set in "COMP" position is automatically solved since the azimuth indicator always indicates the relative bearing of the station.

1. Circulation of Time and Distance: Turn aircraft until the needle indicates 90° or 270°.

2. Note the time and fly a constant magnetic heading.

3. Note the elapsed time to fly an azimuth change of 5° to 20°.

a. The amount of change flown should be regulated according to the amount of time necessary to obtain a definite change.

b. For instance, too much time would be wasted or consumed when flying a 20° change when a considerable distance from the station.

4. Apply the following formula:

$$\frac{60 \times \text{Minutes flown between bearings}}{\text{Degrees of bearing change}} = \text{Minutes from Station.}$$

a. For 5° change: $12 \times T$ = *Minutes from station.*

b. For 10° change: $6 \times T$ = *Minutes from station.*

c. For 15° change: $4 \times T$ = *Minutes from station.*

d. For 20° change: $3 \times T$ = *Minutes from station.*

5. Remember the result will only be an approximation because:

a. The formula applies for solving the radius of an arc while the aircraft is actually flying a tangent to an arc. Therefore, theoretically, the smaller amount of change flown, the better the result.

b. The figure 60 is only a round number of the correct constant.

c. No account is made for wind drift.

6. To compute actual distance in miles from the station;

$$\frac{\text{TAS in MPH} \times \text{Minutes flown}}{\text{Degree of bearing Change}} = \text{Miles from station}$$

Homing

The aircraft is directed toward the station by keeping the indicator needle on "0." The primary source for directional reference will be obtained from the radio compass indicator. The directional gyro will be used for a reference for attitude control.

The direction of deviation of the indicator needle from "0" will indicate the direction in which a correction must be made to keep the aircraft headed toward the station. In all radio compass work the pilot should make a correction as soon as he realizes one is necessary. A 5° deviation will be considerable distance off course when ten minutes from the station, but would only be a small distance when one minute from the station.

The aircraft is turned until the indicator is at "0" meaning that the aircraft is again headed toward the station. Thus, homing

does not include drift correction. When a cross wind exists the resultant flight path will be curved downwind and the magnetic compass heading of the aircraft is turned upwind. The needle fluctuations will become rapid as the station is approached, but no attempt should be made to follow these rapid fluctuations. The station has been passed when the indicator needle moves through the 90° or 270° position of the azimuth scale to a 180° position. Some disadvantages of homing are:

1. *Does not maintain a constant track over ground.*
2. *Requires longer time.*
3. *It is impossible to home away from station.*

Tracking Into A Station (Inbound)

Tracking is a means of homing in which the pilot determines the drift affecting the flight path and corrects for it accordingly.

The directional gyro is used as the primary source of directional reference and the radio compass indicator to determine deviation from a desired track.

The deviation of the needle indicates the direction of the wind and the direction in which a correction must be made. However, the correction must be such as to return the aircraft to the desired track over the ground.

The pilot holds the predetermined directional gyro heading as his track. If a cross wind is affecting the flight path, the needle will move away from "0" in the direction of the wind. As soon as a deviation is noticeable, a correction, by means of a gyro turn, will be made in the direction the needle is deviated from "0". Amount of correction should be sufficient to guarantee return to the desired track and will depend upon rate at which aircraft drifted from track and approximate distance from station. A small angle of drift far out may mean a large distance of drift. As the station is approached the needle indicates a faster rate of drift. Actually, the rate of drift is constant, but the radio compass bearing change is faster. A thirty degree correction applied quickly and properly will be sufficient for a cross wind up to one-half the airspeed of the aircraft.

The needle will then indicate the relative bearing of the station on the opposite side of "0."

The aircraft is back on track when the needle indicates a relative bearing of the same number of degrees as the gyro turn and to the opposite direction from "0" as the correction. Reduce wind correction, holding an estimated amount to keep aircraft on track. As long as the needle deviates from "0" the same number of degrees and in the opposite direction as the applied correction, the aircraft is staying on track. (It will be noticed that tracking is the same procedure as beam following in radio range flying.)

Tracking Away From A Station (Outbound)

Use the 180° marker as a reference index much the same as the "0" marker was used tracking into the station. When making a correction toward a bearing, the needle will indicate farther away from 180°. In other words, the needle moves in the direction of the turn; whereas, in tracking toward a station, it moves opposite to the direction of turn. When the needle comes back to a position which is the same number of degrees from 180° as the applied correction, the aircraft is then on track. Apply a drift correction and hold it. If your applied drift correction is not the correct amount, the indications of the azimuth indicator will be much the same as when tracking into a station.

Interception of Bearings

Turn to the magnetic heading of the bearing to be intercepted. The pointer of the radio compass azimuth scale will point toward the station and the bearing, thus indicating the direction of turn necessary to intercept the bearing. Turn toward the bearing until the pointer is 30° away from the 0° position on the radio compass azimuth scale. The number of degrees of turn necessary to place the pointer in this position is the angle of interception. Hold this interception heading with the directional gyro until the pointer of the radio compass azimuth scale is the same number of degrees away from the 0° position as the angle of interception. Then the aircraft has intercepted the desired bearing.

Interception of bearings is identical with tracking, except that it is on a larger scale.

Holding Procedures

Holding procedures will be identical with those used while flying radio range. The advantage of this is that the pilot can be directed to hold on any outgoing track heading. Instructions will include outgoing bearing on which holding will be accomplished, time between station and procedures, turnaround, and altitude.

Upon reception of instructions, pilot will attain holding altitude and continue to track to station. Upon station passage, turn to holding bearing and track outbound for the required length of time. Turn 45° to left of holding bearing, hold for 40 seconds, and complete a standard rate turn to the right to the reciprocal of holding bearing. Track inbound toward the station. At the station complete a normal procedure turn to the right in the same manner.

ADF Low Approach

Fly over the station. Upon recognition of the station, turn to the reciprocal of the station-to-field bearing, noting the clock. Track out for three minutes on this reciprocal bearing. At the end of three minutes, make a procedure turn to the left, hold for 40 seconds, then a standard rate turn to the right back to the inbound bearing. Track into the station. At station passage, note the clock, and track away from the station letting down to minimum altitude for the station.

Aural Null Procedures

It should be thoroughly understood by the pilot that all null procedures are of an emergency nature. Because of the loss of the sensing antenna or other factors causing the automatic feature of the radio compass to become inoperative, the pilot will find the manual operation of the loop antenna a great aid. The procedures on the null will be found to be similar to both ADF (Automatic Direction Finding) and radio range flying. This will simplify the learning process for the pilot.

At first the manual operation of the loop using the left-right switch may seem quite difficult, but with practice it will become apparent that null procedures are easy and simple and involve only a few extra instruments for the pilot to check.

The Aural Null — What It Is

When the plane or "hole" of the loop is in a position so that it is perpendicular to the station to aircraft bearing, the loop is then at a minimum signal position. This minimum or no signal position is referred to as the aural null. The width of the null, or the number of degrees through which the loop may be rotated and still give no signal, may be varied by the audio control. To widen the null, the audio control must be decreased. The opposite is true when decreasing or "sharpening" the width of the null.

If the aircraft is quite far from the station, it may be found that with full volume, the null is still quite wide. In such a case, the power of the station and the aircraft's distance from it will determine its width.

With the function switch in the loop position, the pilot will find that by use of the left-right control, he can rotate the loop either to the left or right.

A *good* procedure to follow whether going inbound or outbound is to turn the loop opposite to the direction of turn. If the turn is made to the left, by rotating the loop to the right and vice versa, the station will be more easily held.

Orientation and Time or Distance Check

To solve the 180° ambiguity error inherent in all loop antennas, turn the aircraft and place the null in one of the wing tip positions. Then maintain a constant direction by use of the directional gyro until the null has moved at least 5°. If in order to hold the station the loop must be rotated to the left or counterclockwise, the transmitting station lies to the left. If the loop must be rotated clockwise or to the right, the station lies to the right.

During the orientation, it is also possible to make a time or distance check, using the afore-mentioned formulas. Once oriented, always keep the azimuth needle pointed toward the station. This will be of help in remaining

oriented throughout the procedures.

HOMING. When an aircraft homes into a station no correction is made for the wind. Simply turn until the needle is pointed to a nose null. It will be necessary from time to time to turn into the wind in order to keep the null in a nose position. Keep the null at a constant width at all times.

STATION RECOGNITION. The secret of recognizing the station is in keeping the null at a constant width. The best indications that a pilot has of being close to the station are:

1. *The rapidity with which the volume must be turned down in order to keep the null at a constant width.*
2. *In the case of a commercial broadcast station, the relationship between the volume when, using both positions of the CW-voice switch.*

If the aircraft passes directly over the station, there will be a short space of time when the null will be lost completely. If the aircraft passes slightly to one side of the station, it is quite often possible to follow the null around to the tail. If the pilot is sure that he is within a minute of the station, he may rotate his loop to a maximum signal position (wing-tip null) and maintain a constant direction. In this circumstance, when the station is passed, there will be a surge of volume followed by a complete fade of signal which sounds very similar to the cone of silence of a radio range station. Care must be taken when using this method to have the volume at a very low level.

One of the most positive checks is the widening of the null after passing the station. As soon as the aircraft passes the station and proceeds outbound, there will immediately occur a broadening of the null due to the decrease of signal intensity. When the pilot observes this broadening of the null when he has not made a manual volume change, he will know that he has passed the station. The rapidity with which the null will broaden will depend upon the type and power of the station. If it is necessary to work loop procedures on a loop type range station, it is advisable to turn the loop to a maximum signal position and use ordinary radio range procedures.

A good method to check for station passage is to turn to the right or left 30° off the track heading. Follow the null. If it moves closer to the "0" indication, the station has been passed. If the null moves farther away from the "0" indication the station is ahead.

TRACKING INBOUND. Turn the aircraft until the null is in the nose position. Hold the heading constant until the null moves to the left or right of the nose. This indicates that the wind has drifted the aircraft to the right or left of the chosen track. A correction will be made back toward the track. A 30° turn will be ample for crosswinds up to one-half the air speed of the aircraft. The pilot will judge the amount of correction necessary. Keep in mind that the null will move opposite to the direction of turn. Hold this correction until the null has moved the same number of degrees in the opposite direction as the turn. Apply a drift correction. As long as the null is off "0" on the azimuth the same number of degrees as the applied correction, the aircraft is on track.

TRACKING OUTBOUND. It will be of help if the pilot will think of the station as being to the right or left of the tail using the 180° marker on the azimuth indicator as a reference index.

Outbound tracking is exactly similar to inbound tracking. It will be necessary, however, to become familiar with a different indication. When correcting toward the track, the null will move farther away from the 180° marker. In other words, the null will always move to the inside of the turn. When the null moves back to the same number of degrees off the tail as the applied correction, the aircraft is back on track.

INTERCEPTION OF BEARINGS. Turn the aircraft to the heading of the bearing you desire to intercept. The relative bearing of the null will show the minimum angle that may be intercepted. Select an angle of interception and turn the aircraft to the bearing the same number of degrees as the angle of interception. When on track, the null will be the same number of degrees of the nose as the angle of interception.

LOW APPROACH. When aural null procedures are required, identical procedures will be used with those employed for ADF low approaches. Initial approaches will be made from any direction. The station will first be recognized WITHOUT turning the loop to a wing tip null position.

The factor that will determine the type of approach to be used is the distance from station to field. There are two approaches used:

1. *When the distance from station to field is sufficient to allow a let down between the two.*

2. *When the transmitter is directly adjacent to or on the landing field itself.*

If sufficient distance is available to allow the pilot to let down between the station and the field, he will track outbound for two minutes. A normal procedure turn will be accomplished and the track intercepted inbound. A track will be maintained into the station. For the second identification of the station, any of the before stated systems may be employed. Upon recognizing the station, the pilot will assume a rate of let down that will allow him to reach the minimum approach altitude approximately one-half mile from the field. Should the station be very near or on the field itself, a similar but slightly different approach will be employed.

The pilot will track outbound for precisely three minutes. At the completion of that time, a normal procedure turn will be made. Upon intercepting the track inbound, the pilot will begin an immediate descent to final approach altitude at a rate that will allow him to break contact at least one-half mile from the field. All altitudes will be governed by the standard instrument approach for that station.

HOLDING. The holding procedure to be used with aural null operation is identical with that employed for ADF.

POSITION PLOTTING

Many times while dead reckoning, a pilot desires to know his approximate position. It may often be the case that he will be unable to find a contact reference point that he can recognize. At such time, whether above an overcase or contact, the pilot will find the radio compass a great aid in determining this position. In the handling of any radio equipment there are what we may refer to as tricks of the trade. If the radio compass is understood and used to the best advantage, the pilot will find that flying, generally, can be greatly simplified. First, it will be best to consider some general terms used in reference to radio compass position plotting.

Relative Bearing

The relative bearing is the angular difference between the magnetic heading of the aircraft and the magnetic bearing of the station from the aircraft. This angle is always measured clockwise from the nose of the aircraft. In aural null terms, a nose null is a relative bearing of zero degrees.

MAGNETIC BEARING. The magnetic bearing to the station is obtained by adding the relative bearing indicated by the radio compass to the magnetic heading of the aircraft.

TRUE BEARING:

The magnetic bearing corrected for variation.

RECIPROCAL BEARING. When plotting fixes a station to aircraft bearing is used. This is known as a reciprocal bearing and is obtained by adding or subtracting 180° from the aircraft to station bearing. When this bearing is plotted it is referred to as a line of position "LOP".

It is often possible for a pilot to check his ground speed using the above method. After one position on the range leg is determined, by taking another fix a short time after the first and plotting that position, the pilot can determine the mileage, how long it has taken to travel this distance, and compute a ground speed.

In taking running fixes, the factor of time and the ground speed of the aircraft must always be considered. A pilot may desire to know his general position while dead reckoning during contact weather conditions, or if instrument conditions prevail, to determine his approximate location in relation to an-

other radio fix. It is often advantageous to take a running fix on a station to determine an approximate line of bearing from the station. Running fixes are used most frequently, however, on three stations. By taking a "running" on three stations and plotting these bearings on the DF chart, a triangle will be formed. A pilot can approximate his position only near the resulting triangle. Under no conditions must the pilot regard ADF triangulation as exact.

The radio compass set and the range receiver may be used together by tuning both sets to different radio ranges to recognize the intersection of two legs, tuning the range receiver to a range station and the radio compass to a broadcast station, or tuning one to a range station and using the other for communication with a control tower. Only the fundamentals of the radio compass and its use have been explained, and as such will form the foundation for radio compass work. Naturally, every situation will differ slightly, but with thorough understanding of fundamentals, radio compass work will be simple and effective.

RADIO CHARTS

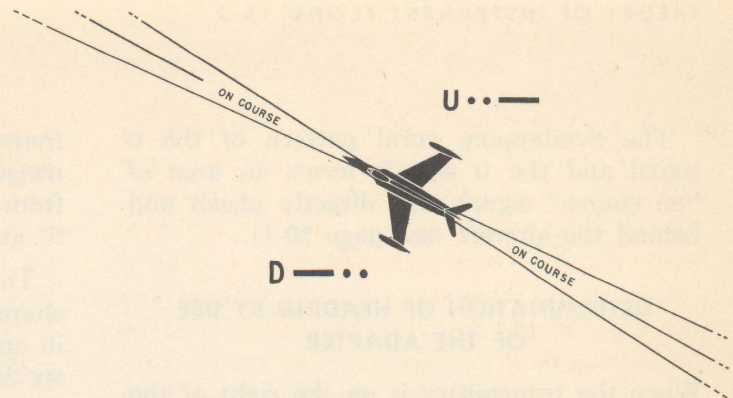
All pilots are familiar with sectional and regional charts which have a scale of 1″ 500,000″ and 1″ 1,000,000″ respectively, and the newly issued AF Aeronautical Chart with a scale of 1″ 1,000,000″. The compass roses indicated on these charts are "TRUE" roses and indicate true courses. The DF chart (Radio Direction Finding Chart) is drawn to a scale of 1″ 2,000,000″. Superimposed around each radio station, (low frequency) is a compass rose which has been corrected for variation. These roses show magnetic bearings. On the inside of the compass roses are printed magnetic headings away from the station as in the standard compass rose. Around the outside in large print are indicated the courses into the station, (the reciprocal of the outbound courses). Therefore, when a DF chart is used, the magnetic headings can be plotted directly and no calculation of reciprocals is necessary.

RADIO FIXES

There are two general types of fixes, "instantaneous" fix and "running" fix. An instantaneous fix is obtained when the bearings used are taken simultaneously. A running fix, however, involves a time lag between the bearings taken.

Instantaneous Fixes

During contact navigation it is often possible to obtain a reasonably accurate fix at the intersection of a radio range leg and a coast line or river. Under instrument conditions, the intersection of two radio range legs is commonly used as a fix. Combination of DF and radio ranges may be employed to advantage. Taking a cross bearing on a station while flying a radio range leg will give a pilot, with reasonable accuracy, his position on the leg. If possible a pilot should choose a radio station whose bearing is as near 90° to the range leg as possible. This will increase the accuracy of the fix.



CHAPTER NINETEEN

Homing Adapter

Most radio compasses and other direction finding devices are relatively complex and occasionally unreliable because of maladjustment or poor maintenance. Also, these aids to navigation rely upon a steady low-frequency signal which often-times is unavailable due to atmospheric conditions. Therefore, a simple, reliable means of direction finding is desirable. Such a device is available to the instrument pilot in the use of the VHF homing adapter, AN ARA-8A.

DESCRIPTION

This equipment, used with the VHF command set, provides a means of aural homing on any transmitted carrier within the frequency range of 120 to 140 megacycles. It has been installed in various types of aircraft, but it is used principally in fighters.

The adapter is used for homing on VHF ground stations to reach a known point or location. The adapter may be used for homing on airborne VHF sets for purpose of guidance or rendezvous. This equipment gives satisfactory performance over a line of sight range even during atmospheric disturbances which normally render the low- and medium-frequency navigational devices unusable.

MAJOR COMPONENTS

There are two VHF antennas used to receive the homing signals. On many aircraft the two antennas, enclosed in wooden masts, are installed side by side on the top rear section of the fuselage; however, on newer type aircraft, a pair of interchangeable antennas set in plastic panels are attached, one on each side of the vertical fin.

The modulator keying unit for coding the incoming signals provides the code characters (D & U) for identification of the semicircle from which the signal emenates. The keying unit is located beneath the two antennas in the aft section of the fuselage in most standard installations. The control unit placed within the cockpit operates the homing adapter and controls the antenna relay unit which connects the VHF set to either the normal communications antenna or the homing adapter antenna system.

PRINCIPLES OF OPERATION

The two antennas and their connections are so arranged as to give a strong signal from a station on one side of the aircraft and a minimum signal from a station on the other side of the aircraft. These connections are alternated from one side to the other by the keying unit.

The keying unit forms the signal received from the right into the coded character U (dit dit dah). The signal from the left is converted into a coded character D (dah dit dit).

The overlapping aural pattern of the D signal and the U signals forms an area of "on course" signal tone directly ahead and behind the aircraft (see page 19-1).

DETERMINATION OF HEADING BY USE OF THE ADAPTER

When the transmitter is on the right of the aircraft's heading, the code signal U is heard in the headset; when the transmitter is on the left the code signal D is heard; when the transmitter is either ahead or behind, a steady tone will be heard.

The signal pattern is a result of the dual antennas on the aircraft. Therefore, the pattern turns as the aircraft turns. The 180° ambiguity can be solved by turning to the right when the U is heard and turning left when the D is heard. If a steady tone is heard first, the aircraft should be turned off course approximately 45° to the right, for instance. Then if a U is heard, continue the turn since the station is behind the aircraft. If the signal D is heard, resume the original heading.

In the immediate vicinity of the station, overloading of the receiver may cause momentary garbling of the signals. This provides the pilot with one means of station recognition, however should the aircraft pass over the station without recognizing it, as soon as the heading deviates from on-course the signal in the earphones will shift to indicate the 180° change of pattern. No 180° ambiguity exists if this simple rule is followed: "U, turn right, D, turn left."

OPERATIONAL INSTRUCTIONS

The aircraft must be in an attitude of straight-and-level flight for the homing adapter to furnish accurate indications of course headings. Homing on one of two stations, both of which are unmodulated and of nearly equal signal strength, is not possible with this equipment. Decreasing altitude or changing positions to find a point where one station is much stronger than the other, enables the pilot to home on the stronger signal.

Homing should not be attempted on any frequency lower than 120 or higher than 140 megacycles. The on-course width will vary from about 35° at 120 megacycles to about 5° at 140 megacycles.

To start the equipment select the VHF channel to be used and place the VHF receiver in operation. Place the switch on escutcheon MX-369 ARA-8 in the HOMING position. If homing is to be accomplished on an unmodulated (CW) signal, place the adjacent switch in the position marked "CW." If homing is to be accomplished on a transmitter sending tone modulated signals, place the switch in the "MCW" position.

To turn the carrier of the VHF set on continuously so that other aircraft may home on your transmission, without the necessity of holding down the microphone button, the "TRANS" switch on the control panel may be used. The transmitter carrier will remain on the air until this switch is returned to either the "COMP" or the "HOMING" position. Volume is controlled through normal use of the VHF volume control.

To stop the equipment, move the homing control switch to the position marked "COMM."

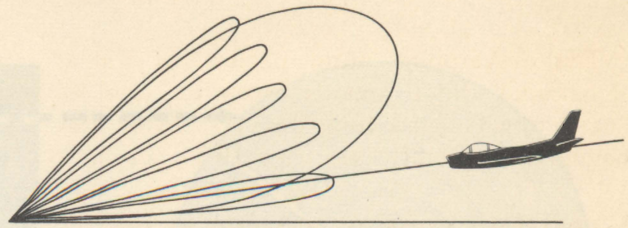
In some aircraft owing to the shape and size of shading areas, (wings, fuselage, nacelles, etc.) it is possible to obtain a false on-course. Usually the same character, U or D will be heard on both sides of the false on-course, thus identifying it as such to the pilot.

VOICE PROCEDURE

Proper procedure for requesting a signal for a heading is, for example: "Barksdale Airways this is Air Force 7890, request steady carrier for one minute, over" The station will reply "Air Force 7890 this is Barksdale Airways, roger, (*steady signal one minute*) this is Barksdale Airways, out."

Proper use of the homing adapter and an understanding of its limitations tend to make instrument navigation problems easier. The frequency of the signal used for homing determines the width of the on-course. Frequencies above 140 and below 120 should not be used.

CHAPTER TWENTY



Instrument Approach Systems

Radio ranges are normally satisfactory for instrument approaches with ceilings at or near 500 feet for a limited number of approaches within a given time interval. Something better than radio ranges is needed to insure scheduled landings and maintain air traffic in any emergency. Research has been carried on for many years, and until recently, this research was aimed toward the development of a blind landing device. The perfection of improved runway lighting and longer runways, however, has changed the goal toward better methods and equipment for making an instrument approach to a position over the runway at an altitude of approximately 50 feet from which point the landing can be completed by visual reference.

Two approach systems have been developed which, despite the fact that they operate on entirely differing principles, accomplish the desired purpose. The first, the USAF Instrument Low-Approach System, enables the pilot to make the approach by visual reference to an instrument on his instrument panel and by checking his distance from the runway through the use of the familiar fan-type marker beacon. The second system, Ground controlled approach, requires no additional equipment in the aircraft, and is simply a "talk-down" method, which uses the aircraft's communication equipment for reception of instructions for the approach from an especially designed ground radar station. Both systems have their advantages and disadvantages. Some of these will be brought out in the descriptions which follow.

GROUND CONTROLLED APPROACH

Ground Controlled Approach uses radar to locate the aircraft when it enters or approaches the control zone and when on the final approach to give accurate information for lateral and vertical guidance to the end of the runway. The equipment presently in use (AN MPN-1) is a mobile installation contained in a truck and trailer, and located to one side of the far end of the runway.

Radar Systems

Two radar systems are employed, and except for the antennas and indicator equipment, there is duplicate equipment for standby use. One radar system is called the search system and the other the precision system. The search system has a rotating antenna and scans an area around the field with a radius of 30 miles, and up to 4,000 feet elevation, with a signal pattern 7° wide in azimuth. This system, operating in the frequency

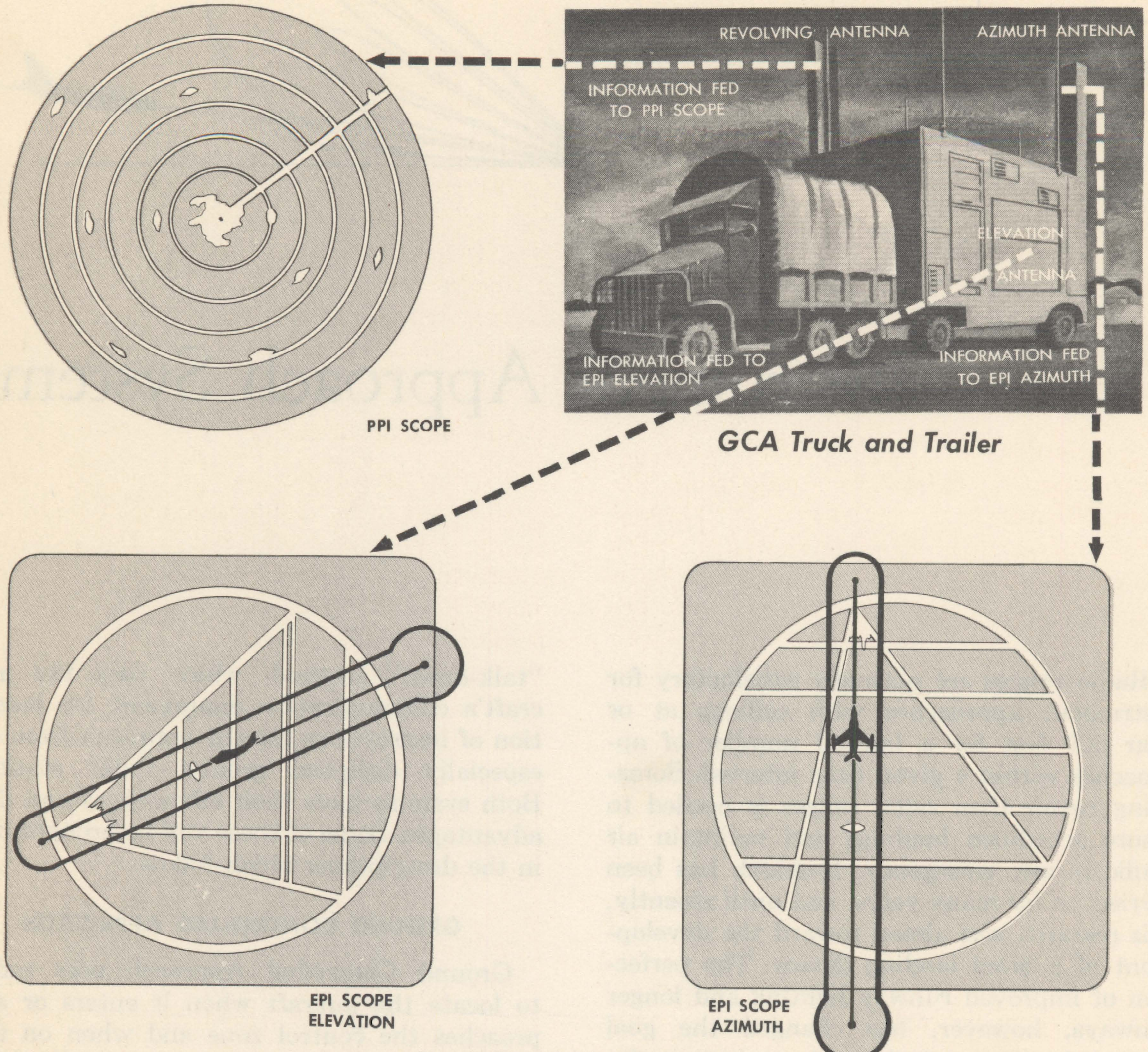
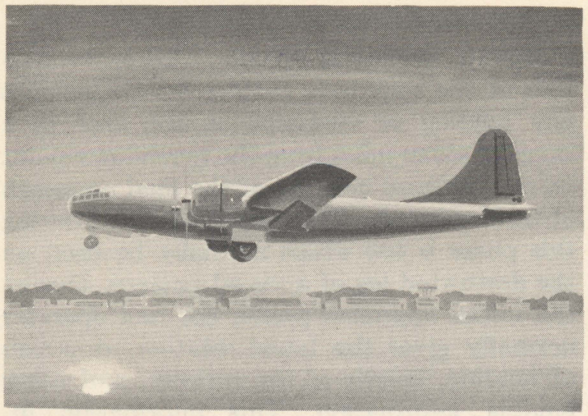


Figure 33—GCA Indicators.

range between 2,700 and 2,900 mc., provides general coverage of the surrounding area and makes possible the control of traffic while aircraft await their turn to land. There are two cathode-ray-tube indicators of the PPI type; each one presents a polar map of the area around the station. Each indicator provides a choice of three ranges, 7.5 miles, 15 miles, and 30 miles. Two operators man these indicators. One, called the traffic director, uses the 30-mile range scale, and the other, called the plane selector, uses the 15-mile range scale.

The precision radar system, operating in the frequency range between 9,000 and 9,180 mc., does double duty. By employing two antennas and sending pulses of radio energy alternately from them, the equipment serves two purposes. One antenna, the azimuth antenna, scans an area of 20° in azimuth and to a distance of 10 miles. Its echoes are fed to two indicators, one with a 10-mile range scale and one with a 2-mile range scale. The other antenna, the elevation antenna, scans an area 7° in elevation and to a distance of 10 miles. The elevation antenna delivers its echoes to two additional indicators with ranges of 2 and 10 miles respectively.

The azimuth and elevation indicators are the EPI (expanded partial PPI) type. The 20°



angle scanned by the azimuth antenna is expanded on the indicators to an angle of 60° for more accurate measurement, and likewise the 7° angle scanned by the elevation antenna is expanded to an angle of 60°. The two pairs of indicators of the precision system are watched by two operators, the azimuth tracker and the elevation tracker. By following the echo on the azimuth indicator with a cursor, the azimuth tracker automatically controls an indicator which shows deviation from the correct path in feet. The elevation tracker also operates a similar cursor which controls another indicator that shows deviation from the correct glide path in feet, above or below. Both operators use their 10-mile indicators until the aircraft is within a range of 2 miles, and then they switch to the 2-mile ndicators for more accurate measurements. The approach controller watches the two indicators showing deviations in feet, and talks the pilot down (Fig. 33).

Normally the Air Force uses a modified practice in operating GCA equipment. A 3-man crew is used, consisting of one man serving as traffic director and plane selector, one as the elevation tracker, and one as the approach controller. The elevation tracker operates his cursor in the manner already described. The cursor actuates the elevation meter which has been moved to the azimuth tracker's position. The approach controller sits in this position and reads azimuth deviations directly from the precision indicators and elevation deviations from the needle-type elevation meter. The needle-type azimuth meter is not used. If traffic is unusually heavy a fourth man can be added to the crew. Then one man serves as traffic director and another one as the plane selector.

Communication Equipment

The communication system provides facilities for communication between the GCA unit, the airfield tower, and the aircraft. There are a number of HF and VHF channels for communication with aircraft by the traffic director, plane selector, and approach controller.

Use of the GCA System

The AN/MPN-1 GCA equipment requires a 3- to 5-man crew for operation. The high cost of the large crew required is the principal disadvantage to the use of GCA. Many versions of improved equipment have been devised. One such system can be operated by one man located in the control tower, although additional operators are required for more than a minimum amount of traffic.

Completing an approach under GCA direction requires teamwork between the pilot and the GCA crew. The principal requirement on the part of the pilot is that he be able to fly basic instruments and be able to follow instructions.

Information concerning the availability of GCA at air bases can be found in Technical Orders No. 08-15-1, and in the Airman's Guide. These publications list the Air Force, Navy, and CAA fields that have GCA facilities, the communications frequencies used, and other pertinent information.

During instrument weather conditions, GCA crews monitor the control zone area with radar and radio constantly and during visual flight conditions some facilities are available for training. Because it takes approximately 30 minutes to get the unit into operation, a pilot must anticipate his requirement for a GCA and alert the crew either by entering a request for such an approach in the remarks section of the clearance form before departure or by notifying an appropriate communications facility en route. Such notifi-

cation should be made as far in advance as practicable.

An actual ground controlled approach is quite simple and there are few procedures to remember. The more important are:

1. *ATC approval is necessary before making a ground controlled approach under weather conditions when the destination is on or involves civil airways.*

2. *Do exactly as the approach controller instructs, and if for some reason his instructions cannot be followed, notify him immediately.*

3. *If no transmission is received during any 3-minute period, while in the GCA pattern, return to the original fix that was given.*

4. *When on the final approach, if no transmission is received during any 5-second period, follow the missed-approach procedure for the particular field and contact the control tower for further instructions.*

5. *Read back all headings and altitudes given, and acknowledge all other transmissions except when instructed by the controller to remain silent during the final approach portion of the approach.*

6. *If necessary, a successful ground controlled approach can be made with only the turn-and-bank indicator, the air-speed indicator, and the altimeter.*

7. *Radio transmissions should be confined to those necessary and as brief as possible, consistent with the use of standard radiotelephone procedures.*

When a pilot has been cleared by ATC for a ground controlled approach, the GCA controller gives instructions to the pilot when he reports his position to a radio facility at or near his destination. These are the initial instructions to the pilot which enable him to get into the GCA traffic pattern. The most common patterns used are the conventional rectangular pattern, and a straight-in approach from a range of ten miles or more. Regardless of the type of pattern flown, the complete approach procedure is divided into four phases: (1) the initial approach, (2) The final approach, (3) the pre-landing phase, and (4) the touchdown and landing roll.

INITIAL APPROACH PHASE. This is the portion of the approach pattern which includes any holding or vectoring in the area to a range of seven miles from the touchdown point on the inbound heading of the final approach at traffic altitude. The proper air speed during this phase is one which normally be used on the downwind leg of a visual pattern. During the initial approach phase, the GCA operator normally gives the latest weather, direction of landing, length of the runway, and other landing information. This information influences the determination of the air speed and the landing flap setting for the final approach phase. If the ceiling and visibility are low, the air speed should be low and the flaps necessarily lowered to give the correct pitch attitude. Also, the shorter the runway, the lower must be the air speed. In no case should the air speed be more than 30 miles above the stalling speed for the aircraft as determined from its gross weight. Flap settings are dependent upon the speed to be held on the final approach. When a great amount of flaps is necessary to maintain the proper attitude, the additional flaps should not be added until the aircraft is on the final approach at a range of approximately 7 miles.

FINAL APPROACH PHASE. The final approach phase is the portion of the pattern extending from a range of 7 miles to the instant the aircraft breaks through the overcast and visual reference to the ground is established. At a range of 7 miles the aircraft is slowed to the final approach speed, and the traffic altitude maintained until instructions are received to start a descent along the glide path.

PRE-LANDING PHASE. The pre-landing phase is that portion of the pattern flown after breaking out of the overcast until just before contact is made with the runway. It is the period of transition from instrument flying to visual flying. During this phase the changeover from the controlled flight by the GCA crew and visual flight by the pilot should be gradual, with the pilot continuing to adhere to the instructions given by the controller until it is very evident that he will not iose visual contact with the ground.

Touchdown and landing roll. During this phase the approach controller notifies the pilot when the aircraft is over the end of the runway. If visual contact has not been established by this time and the aircraft is in a landing attitude with a rate of descent less than 500 feet per minute, it is possible to execute a landing by maintaining this attitude until runway contact is made. Such a landing will not normally damage an aircraft structurally. If visual reference is made prior to touchdown, a normal landing should be executed. It should be remembered, however, that there should be no hesitancy to "go around," and that overshooting is dangerous.

INSTRUMENT LOW-APPROACH SYSTEM

The Instrument Low-Approach System, formerly designated the SCS-51, is the Air Force system of instrument approach which makes use of radio transmitting equipment on the ground and receiving equipment in the aircraft to provide the pilot with a visually indicated path to the runway, and marker beacon signals at points at known distances from the runway. The CAA uses similar equipment at many airports, known as the instrument landing system, or ILS. The principal difference in the two systems is that the Air Force ground equipment is mobile.

The system may be divided functionally into three parts, the localizer, the glide path, and the marker beacons.

GROUND EQUIPMENT

The ground equipment consists of two highly directional transmitters, and along the approach, three or less marker beacons. The directional transmitters are known as the localizer and glide path transmitters.

The localizer transmitter, located at the far end of the runway, sends out signals which enable the pilot to steer the required course to the runway. The transmitter, operating on one of six channels within the range of

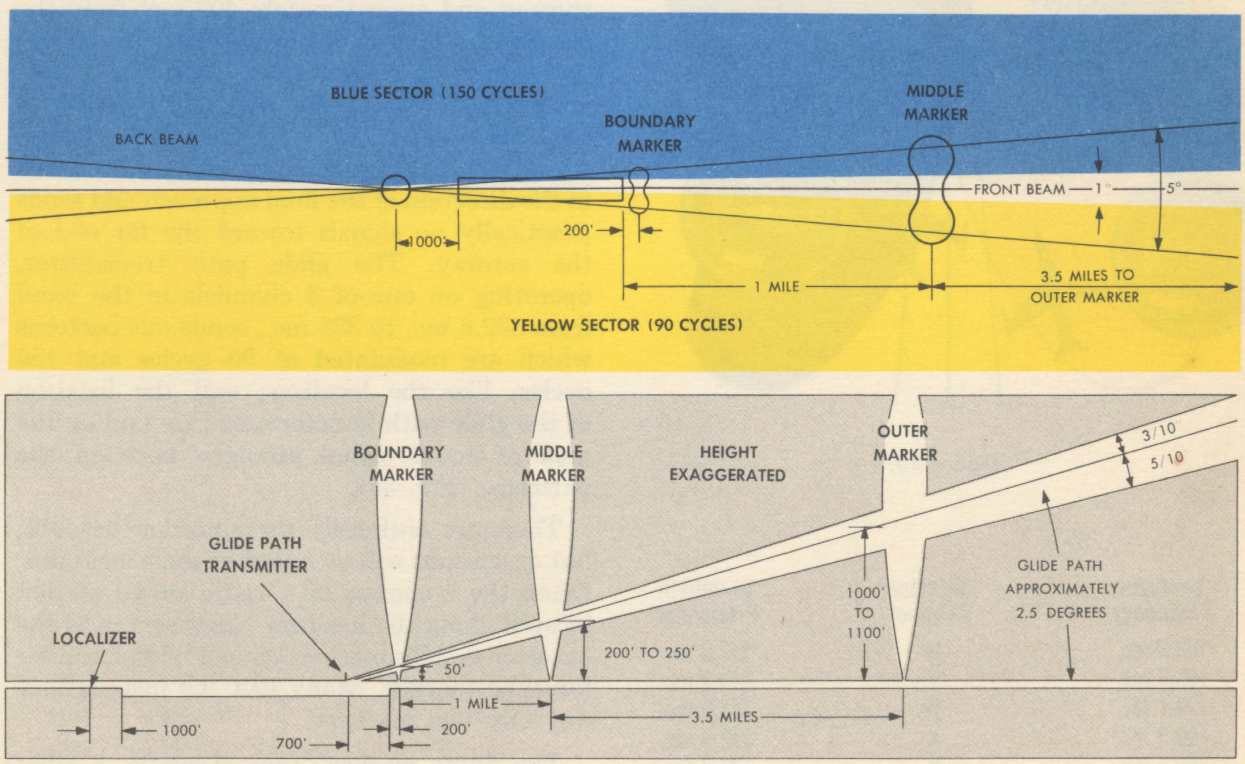


Figure 34—Glide path installation and marker beacons.

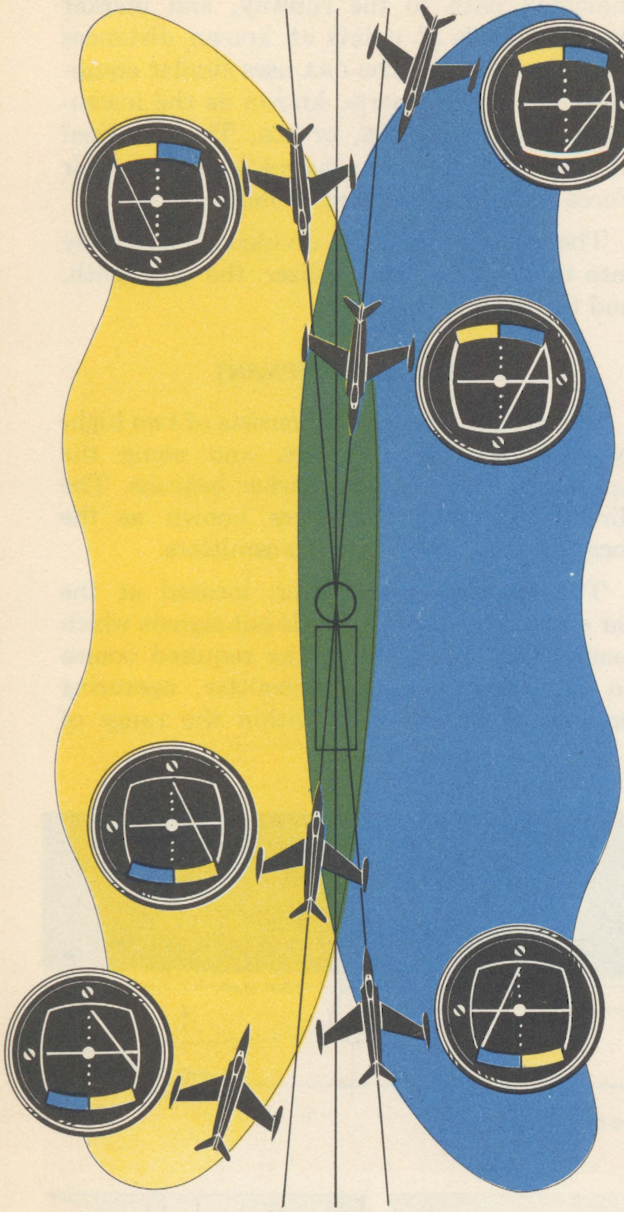


Figure 35.

Localizer Frequency	Selector Channel	Glidepath Frequency
108.3 mc.	U	332.6 mc.
108.7 mc.	V	333.8 mc.
109.1 mc.	W	335.0 mc.
109.5 mc.	X	332.6 mc.
109.9 mc.	Y	333.8 mc.
110.3 mc.	Z	335.0 mc.

108.3 mc. to 110.3 mc., sends out two patterns modulated at 150 and 90 cycles per second. These two signal patterns overlap along a line formed by an elongation of the runway. This line, or course, is determined by the aircraft receiving equipment by finding the area of equal signal strength between the two patterns, just as the course of a radio range is the area of equal signal strength between two quadrants. The course formed by the localizer signals has an over-all width of 5°.

For the purpose of reference, the 150-cycle area to the right of the approaching aircraft is called the blue area, and the 90-cycle area to the left of the approaching aircraft is called the yellow area. The approach course of the localizer is called the front beam, and the course along the centerline of the runway in the opposite direction is called the back beam. The localizer transmitter has a range of approximately 40 miles at an altitude of 5,000 feet, and 80 miles at 10,000 feet.

The glide path transmitter, located approximately 750 feet from the approach end of the runway and approximately 400 feet from the center line of the runway, transmits a glide path beam 0.8° wide, at an angle of approximately 2.5°. The beam may be adjusted to angles between 2° and 4°. Unlike the localizer, the glide path transmitter emits its signals in the direction of the final approach and sends practically no signals toward the far end of the runway. The glide path transmitter, operating on one of 3 channels in the band from 332.6 mc. to 335 mc., sends out patterns which are modulated at 90 cycles and 150 cycles, like the localizer; and the location of the glide path is determined by finding the area of equal signal strength between the patterns. (Fig. 35).

There are ordinarily three marker beacons, but exceptions will be found in some locations. Often the Z-marker of a radio range station located along the localizer beam serves as the outer or middle marker instead of the regular fan-type marker. Many CAA ILS installations use only two markers.

The outer marker, approximately 5 miles from the approach end of the runway, and

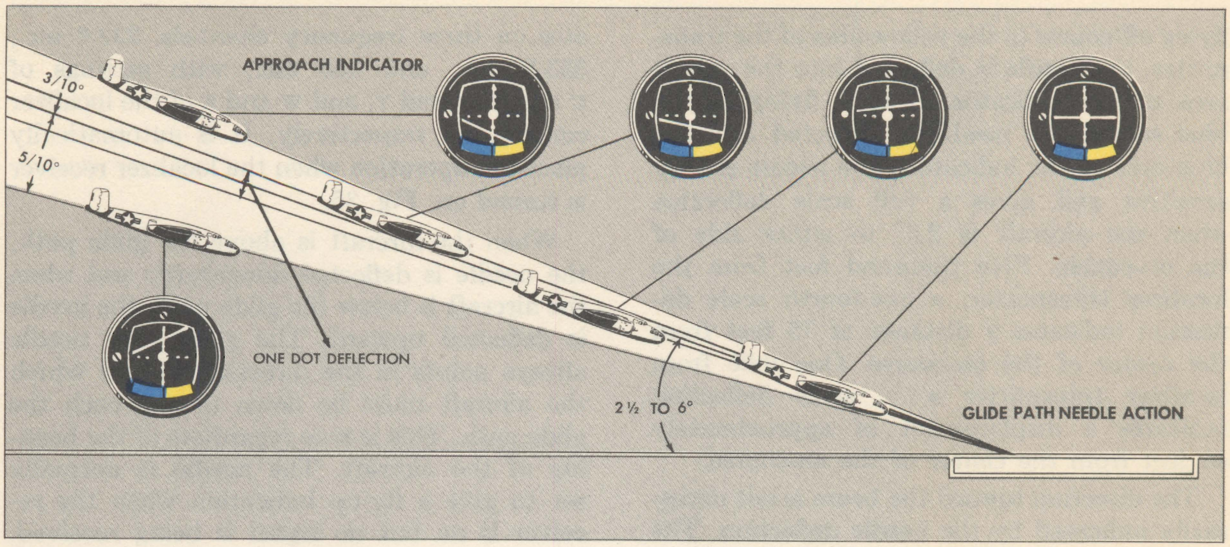


Figure 36—Glide path needle action.

within 250 feet of an extended center line of the runway, emits a signal keyed at two dashes per second. The middle marker, between approximately 3,500 feet and 1 mile from the runway and within 250 feet of the center line, transmits a series of alternate dots and dashes. The boundary marker is placed from 225 to 275 feet from the approach end of the runway and within 200 feet of the center line. It transmits six dots per minute. The distances given for all three markers are subject to variation because of terrain, structures, and other local situations that affect the location of the marker transmitters. Some older installations may be found in which the middle marker transmits a series of dots and the boundary marker a solid unkeyed signal.

Compass locator transmitters are often situated at the middle and outer markers. The transmitters have a power output of 25 watts and a range of not over 50 miles. These stations are being modified to transmit identifying signals consisting of the first two letters (at the outer marker) and the last two letters (at the middle marker) of the localizer 3-letter identification (Fig. 34).

AIRBORNE EQUIPMENT

To enable the pilot to follow the two beams, the aircraft is equipped with an instrument, called an approach indicator, which has two crossed indicating needles, one vertical and one horizontal. The vertical needle supplies a visual indication of the lateral position of the aircraft with respect to the on-course of the localizer. The horizontal needle gives fly-up and fly-down indications which enable the pilot to locate and keep the aircraft on the glide path beam. When the aircraft is properly aligned on the approach, path the needles of the approach indicators are crossed in the center of the instrument.

The localizer receiving equipment filters the 90-cycle and 150-cycle components of the localizer signal and applies them to opposite sides of the localizer needle of the approach indicator. The needle indicates the color area of the sector in which the aircraft is flying—yellow or blue. If the aircraft is

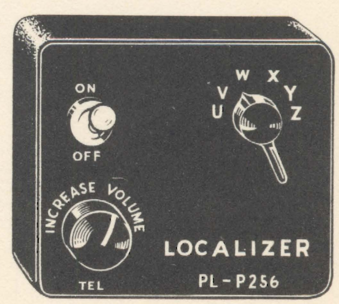


Figure 37—Localizer control box.

flying off-course in the yellow area of the transmitter, the needle is deflected into the yellow area of the indicator. If it is flying in the blue sector, the needle is deflected into the blue area of the indicator. The needle is very sensitive and gives a full scale deflection when the aircraft is 2.5° to either side of the on-course. Five thousand feet from the localizer transmitter, a one-fourth scale deflection indicates a distance of 75 feet from the center of the on-course. One mile from localizer transmitter a 1/5 scale deflection indicates a displacement of approximately 46 feet from the center of the on-course.

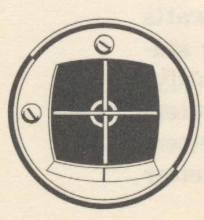
The direction toward the beam is not necessarily indicated by the needle deflection. The indicator has its blue area on the left and yellow on the right in order to make the needle directional when the aircraft is approaching the runway on the front beam. When the aircraft is flying toward the runway on the front beam, or away from the runway on the back beam, *follow the needle*. When the aircraft is flying away from the runway on the front beam or toward the runway on the back beam, *fly away from the needle*. Regardless of the position or heading of the aircraft, the needle is always deflected to that color area in which the aircraft is flying.

The localizer control box contains an on-off switch, a volume control, and a 6-position channel selector with markings of "U" through "Z". The volume control adjusts the volume of the localizer signal in the headset and has no effect on the sensitivity of the needle. (Fig. 37).

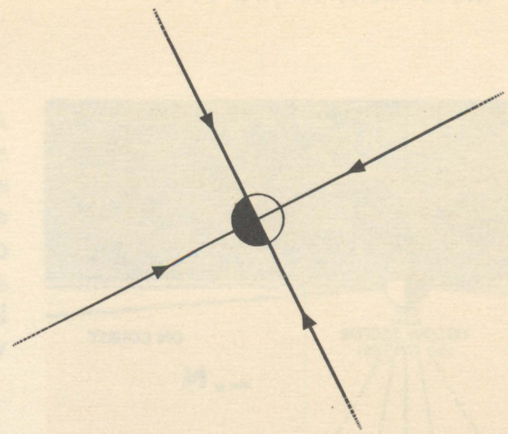
The glide path receiving equipment operates on three frequency channels, 332.6 mc., 333.8 mc., and 335 mc., with settings of U and X, V and Y, and W and Z of the localizer control box respectively. It is automatically placed in operation when the localizer receiver is turned on. Fig. 35.

When the aircraft is above the glide path, the needle is deflected downward; and when the aircraft is below the glide path, the needle is deflected upward. The glide path needle always points in the direction toward which the aircraft must be flown to approach the glide path. This is true regardless of the heading of the aircraft. The needle is normally set to give a fly-up indication when the receiver is on but no signal is being received. The newer type indicator (ID-48) gives an on-course indication when the receiver is off, or not functioning properly, but an OFF flag is displayed over the horizontal needle. When glide path signals are being received, the flag rotates out of sight. The glide path needle gives a full-scale deflection when the aircraft is 0.5° below or 0.3° above the glide path. This requires that the aircraft be aligned quite accurately on the glide path at some distance from the field. Only very minor corrections are allowable near the ground. (Fig. 36).

The antenna system most generally used for the localizer and glide path receivers combines the two antennas on a single mounting. The two elements of the localizer antenna are bent backward into a U-shape, while the glide path antenna elements are mounted in a straight line, parallel to the lateral axis of the aircraft.



CHAPTER TWENTY-ONE



Visual Aural Ranges (VAR)

The availability of the four-course low-frequency range is limited by atmospheric conditions. During periods of heavy precipitation, static and crash static discharge, the use of any low-frequency aid to navigation is either partially impaired or totally lost. Monitoring the aural signal demands the full attention of the pilot, and, in conditions of heavy static, it increases the tension of precision instrument flight which materially lowers the pilot's efficiency. Therefore, a four-course radio range system, embodying the safe and economical features of the low-frequency range plus the refinements of a visual signal upon a static-free frequency, is highly desirable.

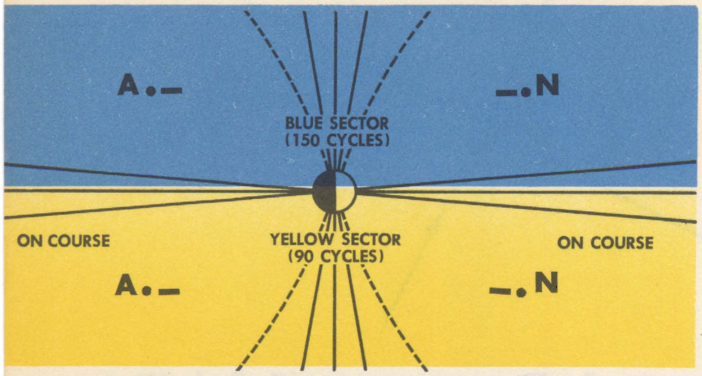
Flight procedures employed with the VAR are essentially the same as those used for the low-frequency range; however, a small amount of practice is required by most pilots who have not had experience with the visual indicator.

Although the advantages of VAR far outweigh its disadvantages, the pilot must fully acquaint himself with the few limitations in its use. Having done this, the pilot may rightfully place his confidence in the VAR and use it to his best advantage.

CONSTRUCTION AND OPERATION

The transmitter is enclosed in a weatherproof structure mounted upon an artificial ground. The station is usually sited upon the highest terrain in such a position as to provide a clear line of sight to the horizon. Obstructions, such as trees, buildings and hills adjacent to the transmitter reduce the usable range of the signal. The distance at which the pilot is able to receive the range signals is dependent upon the altitude of the aircraft and any intervening terrain features. In all cases, there must be a direct "line of sight" between the transmitter and the aircraft for proper reception. This is a distinct disadvantage for flights conducted at relatively low altitudes or over mountainous terrain.

A portion of the antenna array transmits an aural pattern which is similar in some respects to the pattern produced by the conventional LF radio range. A radio wave modulated with the letter "N" (—.) is radiated from one side of the station and a radio wave keyed with the letter "A" (.—) is transmitted on the opposite side. This produces two signal sectors with an equisignal zone between them where the A and N signals overlap to form the solid tone on-course (Fig. above). A bisignal zone adjacent to and on either side of the on-course leg is very similar to that of a four course range. Coded station identification signals are transmitted at 30-second intervals, first in the N sector and then in the A sector.



A two-sector pattern is produced by the "visual" transmitter. One sector is modulated with a signal of 90 cycles per second and the other is pulsed at 150 cycles per second. The two-signal sectors overlap in such a manner as to produce an on-course or an area of equal signal intensity (see Figure 38.)

By combining the aural and the visual signal patterns, a four-course range is produced. Each quadrant is separately identifiable by an aural signal and a visual indication.

RECEIVER EQUIPMENT

Radio receiving set RC-103-A is used to fly the VAR. This is the same set that is used to fly the USAF ILAS (SCS-51). The volume of the aural signal is controlled either at the jackbox or at the ILS control box. Reception of the 90-cycle signal is indicated as a deflection of the vertical needle into the yellow field. Reception of the 150-cycle signal causes the needle to indicate in the blue.

DESIGNATION OF SIGNAL SECTORS

Since the visual course of the VAR is easiest to fly, the signal pattern is always oriented so that the visual legs lie along the airway. On Green and Red airways the blue sector is to the north of the visual course, the yellow sector to the south; the N sector lies to the east of the aural course, the A to the west. On Amber and Blue airways, the blue sector lies west of the visual course, the yellow to the east; the N sector is to the north, the A south. In every case, the pilot will check the placement of the signal sectors in the Technical Order No. 08-15-1, Radio Facility Chart. The visual legs are identified by the symbol "V" following the magnetic inbound heading. Aural legs are identified by the symbol "A" after the magnetic inbound heading. The A section is indicated by the black semicircle at the station, the N sector by the open semicircle. The color areas of the visual pattern are identified by the words "blue" and "yellow" written on the appropriate side of the visual leg.

FLIGHT PROCEDURES

As previously mentioned, the pilot will find reference for the VAR in the Radio Facility Chart; to use the equipment properly, he will follow the procedures listed below:

1. *Turn the receiver set* ON *and select the channel for the frequency of the range. Three channels are normally used: U, 108.3 mc., V, 108.7 mc., and W, 109.1 mc.*

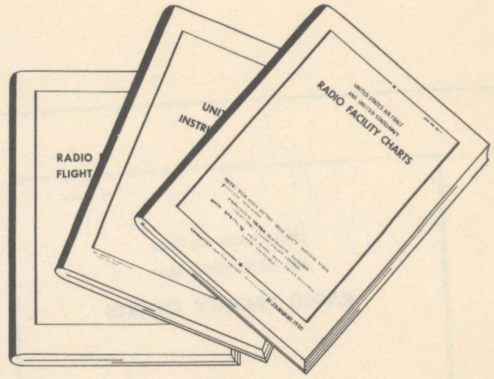
2. *The volume should be set at a comfortable level and the station call letters checked for proper identification. The visual indicator shows the aircraft's position in the visual pattern and the horizontal needle remains in the full UP position.*

3. *Since the four quadrants are each well defined by a combination of visual and aural signals, there is no need for an orientation procedure. The pilot may fly the quadrant bisector heading toward the station, or if he desires, fly a heading perpendicular to the leg he wishes to intercept. Technique in following the beam is identical to that employed on the ILS and the four-course LF range.*

4. *Station recognition is indicated by an aural signal change if following the visual leg to the station, usually accompanied by a rapid oscillation of the vertical needle. The visual indicator will show a full-scale deflection from one color sector to the other as the aircraft passes the station on the aural beam.*

The VAR represents a stage in the development and improvement of better radio aids to aerial navigation. The qualified instrument pilot may place his confidence in the reliability of the VAR even during conditions of heavy static which normally render low-frequency aids unusable.

CHAPTER TWENTY-TWO



Navigational Publications

An instrument flight requires a great deal of planning; the more intense the weather situation, the more careful the planning has to be. To help you in making preparations to cope with these problems, operation officers have available pamphlets, charts, books, and technical orders which may be used to aid the pilot in planning a flight. It is not necessary to memorize the contents of these references, but it is necessary to become as familiar as possible with their contents.

This flight planning involves preparation for the following problems:

1. Choice of airfield for destination—Can the airfield be legally used? Are the landing, lighting, and servicing facilities, radio aids, and other necessary accommodations adequate?

2. Choice of intermediate refueling stops—What is the mileage to destination? How much fuel will be consumed? What cruising range? What are the suitable airfields which are well within cruising range (considering fuel necessary to comply with instrument flight rules)?

3. Choice of route and attitude—What kind of weather will be encountered? Will the flight be VFR or IFR? What is the terrain like? What should be the minimum altitudes, correct altitudes along the airways, control zone, and danger areas? What radio and other navigational aids are available along the route? What are the approved letdown procedures, field elevations, etc?

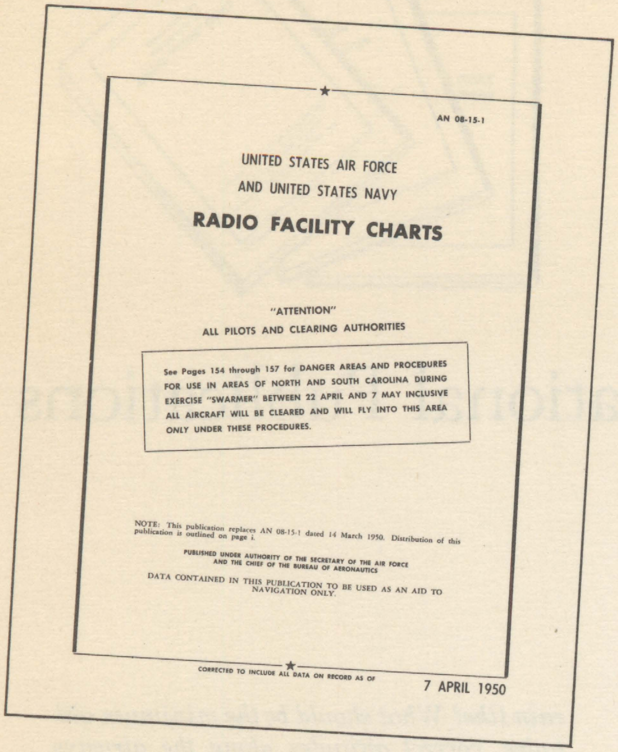
4. Choice of alternate—Does the airfield at the alternate destination meet all of the requirements of the airfield at intended destination? What should be the route and altitude from destination to alternate? (This should be planned in the same manner as the route and altitude to the destination.)

5. Plotting course—What are the proper aeronautical charts? How should the course be drawn? What headings and mileages should be entered?

6. Compiling flight log—What fixes, frequencies, call letters, headings, distances, ETE's, etc., should be entered on the flight log forms?

7. Completing Clearance Form—What is the weather situation for section C? What are the specific points of navigational data to be entered on the form?

8. In-flight flight planning—How are position reports given? How should flight plans be changed? How will instrument letdown and landing be made?


AN 08-15-1

UNITED STATES AIR FORCE
AND UNITED STATES NAVY

RADIO FACILITY CHARTS

"ATTENTION"
ALL PILOTS AND CLEARING AUTHORITIES

See Pages 154 through 157 for DANGER AREAS AND PROCEDURES FOR USE IN AREAS OF NORTH AND SOUTH CAROLINA DURING EXERCISE "SWARMER" BETWEEN 22 APRIL AND 7 MAY INCLUSIVE ALL AIRCRAFT WILL BE CLEARED AND WILL FLY INTO THIS AREA ONLY UNDER THESE PROCEDURES.

NOTE: This publication replaces AN 08-15-1 dated 14 March 1950. Distribution of this publication is outlined on page i.

PUBLISHED UNDER AUTHORITY OF THE SECRETARY OF THE AIR FORCE AND THE CHIEF OF THE BUREAU OF AERONAUTICS

DATA CONTAINED IN THIS PUBLICATION TO BE USED AS AN AID TO NAVIGATION ONLY.

CORRECTED TO INCLUDE ALL DATA ON RECORD AS OF

7 APRIL 1950

Figure 39—AN 08-15-1, Radio Facility Charts.

Navigational problems of flight planning discussed can be readily and easily solved by reference to available publications.

RADIO FACILITY CHARTS

The Radio Facility Charts (AN No. 08-15-1) is one of our most widely used publications (see Fig. 39.) It will be found in the operations office and is available in all radio equipped military aircraft. This publication is completely revised and new copies are distributed to all bases every two weeks. The greater part of the publication is devoted to chart pages of radio facilities with accompanying "tabulation" pages of information. Figure 40 is an example of a chart page with an explanation of the symbols attached.

Minimum En Route Instrument Altitudes

Altitude levels shown on the charts apply to the airway between radio ranges. Safe altitude levels are based on a 1,000-foot terrain clearance, 5 miles to either side of the center of the airway and each section. Flight levels are specified in true altitude feet above sea level. Indicated altitudes may vary considerably from true altitudes, and higher levels should be used in case of doubt as to temperature and/or barometric changes. The established minimum altitudes are those within the actual limits of the civil airways, (5 miles either side of the center thereof) and IFR flights are not to be conducted at lower than those specified therein.

Fig. 41 shows a portion of a "tabulation" page from the Radio Facility Charts. All abbreviations used in the "Class of Station" column are explained on the "Legend and Information" page in the front. All other abbreviations and symbols are self-explanatory.

To clarify the radio facility information further, there are enlarged chart pages in the rear of the publication to be referred to when flight is conducted in a congested area; such as New York, Chicago, Oakland and Los Angeles. Each of these enlarged chart pages has an accompanying tabulation page.

Additional Information

The following is some additional information given in the Radio Facility Charts:

1. *Index to Radio Facility Charts—The index, which is located on the back of the publication, provides an easy method of finding the desired chart page.*
2. *Range Station and "H" Facility Index—This index provides an easy means of identifying any call signs which the pilot may receive and not readily know the transmitting station.*
3. *Omnidirectional and VAR Ranges—A complete listing is given of all VOR (VHF Omnidirectional) and VAR (Visual-Aural) ranges with chart pages showing locations, and tabulation pages with descriptions of facilities connected with each range.*
4. *X-band Radar Beacons—Included here is a complete outline of the X-band beacons as to location, code, operation and hours of operation.*
5. *VHF/DF Stations—A chart page and an explanation page are combined in this*

1. *Pressure conversion tables.*
2. *Broadcasting stations (entertainment band) to be used as aids to navigation.*
3. *Standard time signals.*
4. *Time and distance graph for computing ETA's.*
5. *Conversion tables.*
   a. *Nautical to statute miles.*
   b. *Degrees centigrade to degrees Fahrenheit.*
6. *Distress signals.*
7. *A digest of Civil Air Regulations.*
8. *Accident and forced landing information.*
9. *Hand taxi signals and visual emergency signals.*
10. *Air Force air rescue service.*
11. *Air Force Form 15 information.*

PILOT'S HANDBOOKS

The Pilot's Handbook of the Continental United States, called "PHACUS," is issued in two volumes, one for the East U. S. and one for the West U. S. Both volumes are placed in airplanes based in this country. Handbooks for various areas outside the United States are published and made available for use within the areas of flight. These loose-leaf publications contain four types of charts. The "Instrument Approach Chart—Range" has on the reverse side a "Landing Chart" for the particular base. The "Instrument Approach Chart ILS" has on its reverse side an "ILS Procedure Chart." Sample range and landing charts are included at the end of this chapter.

Use of Instrument Approach Charts

INITIAL APPROACH ALTITUDE. This term applies to the lowest permissable altitude between the last radio fix and the range station. The initial approach altitude on any leg must be at least 1,000 feet above all terrain and obstacles and five miles on each side of the center line of such leg between the last radio fix and the range station. In determining the last radio fix before reaching the range station, only a range station or intersection will be used. Radio fixes seven miles or less from the range station will not be considered. Where no radio fix exists on the off airways legs of a radio range, the phrase "minimum en route altitude" will be used (not stating figures).

PROCEDURE TURN. This is a standard-rate turn used in all procedures and is executed by turning off course 45° in the direction indicated for a stated time, and making a 180° one minute turn away from the station to return to the on-course signal and establishing a heading toward the range station. The distance from the range station to the procedure is stated in miles. The altitude specified for the procedure turn is calculated to insure 1,000-foot terrain clearance throughout the maneuver.

FINAL APPROACH ALTITUDE. This is the lowest altitude which will clear all terrain between the procedure turn and the range station by at least 500 feet. It is the proper altitude to cross the range station for the final approach to the field. Provided the procedure turn is completed within 10 miles of the range station.

MINIMUM ALTITUDE OVER AERODROME. After crossing the range station at the final approach, or low-cone, altitude the letdown is continued to the published "minimum altitude over aerodrome." Visual contact with the ground should be established on or before reaching this altitude. If contact is not made, an immediate climb is commenced and the missed-approach procedure followed. The minimum ceiling for the base is indicated in parentheses along with the minimum altitude over the aerodrome. The range chart includes a time table in minutes and seconds to the landing field from the range station at various speeds in mph and knots.

MINIMUM ALTITUDES. Minimum altitudes are shown in the four quadrants of the range for distances up to 25 miles from the range station. These altitudes will be maintained if any doubt exists as to the exact position of the aircraft.

AIRMAN'S GUIDE (AIRGI)

This is a civilian publication distributed every two weeks by the Department of Com-

merce. It is designed primarily as a guide for civilian pilots and gives them an inexpensive source of aeronautical information. It serves as a means of bringing our Air Force publications up to date. It contains very complete information on the following subjects.

1. *Instrument Landing Systems (ILS)—Here are shown frequencies, headings, locations, and marker beacons information for all Air Force and CAA instrument landing systems.*

2. *GCA—Ground controlled approach information in this publication is the same as that furnished in the Radio Facility Charts.*

3. *Directory of Airports—This includes a list of all fields in the United States with complete information on each.*

4. *Notices to Airmen—This section lists "special notices" first and then lists items which might be hazards to flight at various fields throughout the United States.*

EMERGENCY OPERATION FILE (TRANSITION TRAINING FILE)

This is a file of Technical Orders on pilot's operation instructions and emergency procedures for all types of aircraft. It is kept in operations available to pilots and also available to the tower operator in the event that he might receive a request for such information from a pilot who had an emergency in flight.

AIR FORCE AND LOCAL REGULATIONS

These include all pertinent Air Force flying regulations, as well as local Command and Base flying regulations. These are for the pilot's reference and are the determining factors for clearance approval.

DANGER AREA MAP

A large map of at least 500 miles radius is displayed prominently in operations. It shows all danger areas within that radius of the base. (Most operations offices display a map of the entire United States.)

TELETYPE NOTICES TO AIRMEN

Throughout the year climatic conditions (snow, storms, floods, etc.) render many fields temporarily unusuable or unsafe. In addition there are intermittent maintenance operations in progress on many fields. Radio facilities may suffer temporary power failures or course misalignments, and lighting facilities may fail. Because these temporary conditions cannot be given immediate coverage in the navigational publications a system of Teletype NOTAMS brings such conditions to the pilots' attention almost immediately. These NOTAMS are displayed in a prominent file in the operations office. NOTAMS are covered under three general types which are explained below:

1. **FILLI**—This refers to a notice concerning landing field and lighting equipment.

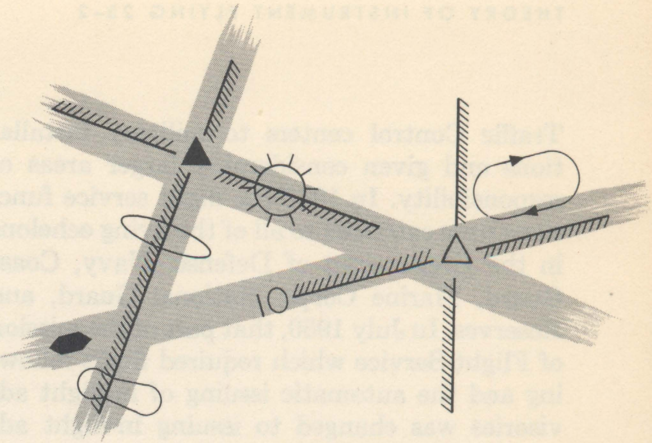
2. **ROCOM**—This refers to any notice about radio communications.

3. **MISEL**—This means miscellaneous and refers to any notice which cannot be covered under the first two classifications.

FOREIGN NAVIGATIONAL AIDS

Aeronautical Chart Service makes available maps, charts and publications to cover all areas in which U. S. aircraft fly. Aeronautical charts, including WAC charts and flight strips, are published for all regularly travelled air routes. Radio Facility Charts for the foreign areas give complete and accurate information about all radio navigational aids. Pilots' Handbooks are published to give safe approach letdown procedures for all stations outside the United States that are utilized by military aircraft. AACS maintains a continuous check on all its radio facilities and reports all dangers to the pilot through appropriate channels.

The Air Force goes to great expense to keep its pilots supplied with the latest accurate information necessary to conduct safe flight under any conditions and in any part of the world. Many accidents can be directly attributed to a pilot's lack of knowledge of facilities available to him. It is to each pilot's advantage to acquaint himself with these.



CHAPTER TWENTY-THREE

Flight Service

HISTORY

During the early years of World War II, the tremendous increase in military flying, with the attendant large number of accidents, brought out the need for supervision of military aircraft movements.

In February 1943 the AAF requested that the CAA handle VFR flight plans, in addition to the IFR flight plans already handled by that agency. This request was approved, and a new AAF organization, known as Flight Control Division, was created in the fall of 1943. The actual operations went beyond flight control and included a Warning Service so that assistance and guidance could be given to all AAF aircraft in the form of "in-flight advisories."

The only existing communications network which had contact with all military air bases was operated by the CAA. The flight control centers were located, therefore, in the CAA Air Traffic Control centers (CAA ARTC). The primary function of the Flight Control centers was to review flight plans for all AAF aircraft, and, if a dangerous condition arose along the route of flight, to advise the pilot of the danger.

In 1944, two additional missions were given to Flight Control. These new missions were: to conduct communications search for overdue aircraft, and, when necessary, initiate search and rescue procedures, and to plan for and supervise the evacuation of military aircraft located in the paths of hurricanes. During the same year, the Flight Control Division was redesignated Flight Service (FS).

In 1945, the Air Communications Office recommended that the AAF establish its own communications system for handling AAF "company business." In 1946, Flight Service was assigned as one of the services of the Air Transport Command. To support Flight Service and handle "company business," what is known as plan 62 was then put into operation. This plan 62 was, and still is, an Air Force communications system, utilizing leased long distance telephone lines and teletype circuits to connect Flight Service centers with each other and with CAA Air Route Traffic Control centers, the AACS airways stations, and all AF bases. The messages handled by this communications net are limited to those which concern the movement of aircraft.

Later, as a result of conditions brought about by the demobilization and resulting cutbacks in appropriations, the Flight Service centers were moved from the CAA Air Route

Traffic Control centers to military installations and given considerably larger areas of responsibility. In 1948 the flight service functions were extended to all of the flying echelons in the Department of Defense: Navy, Coast Guard, Marine Corps, National Guard, and Reserves. In July 1950, that part of the mission of Flight Service which required flight-following and the automatic issuing of in-flight advisories was changed to issuing in-flight advisories only when requested.

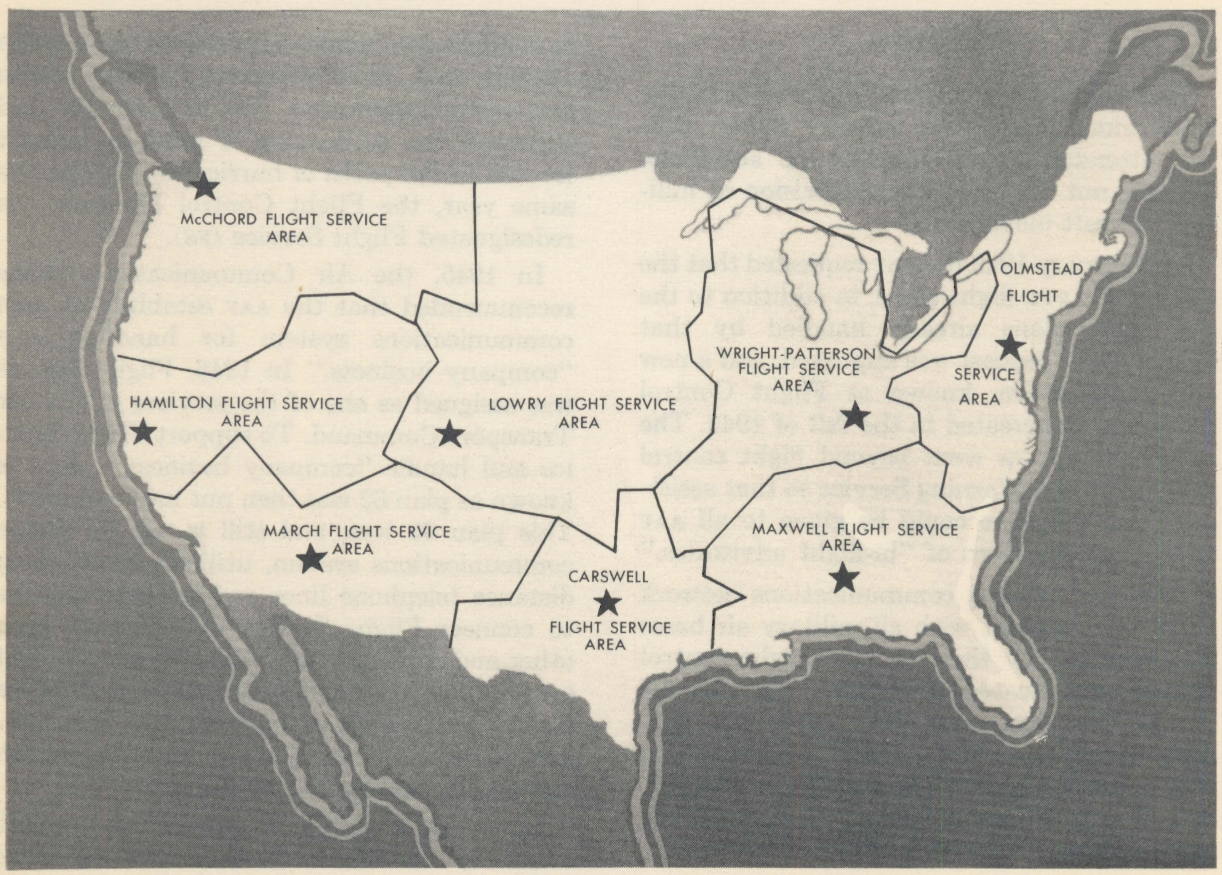
When the Air Transport Command was redesignated Military Air Transport System (MATS) in 1947, Flight Service was included in this command as one of the operational services, along with Air Rescue, AACS, and Air Weather Service. The Flight Service headquarters is located in Washington, D. C., close to the agencies with which it must coordinate.

ORGANIZATION

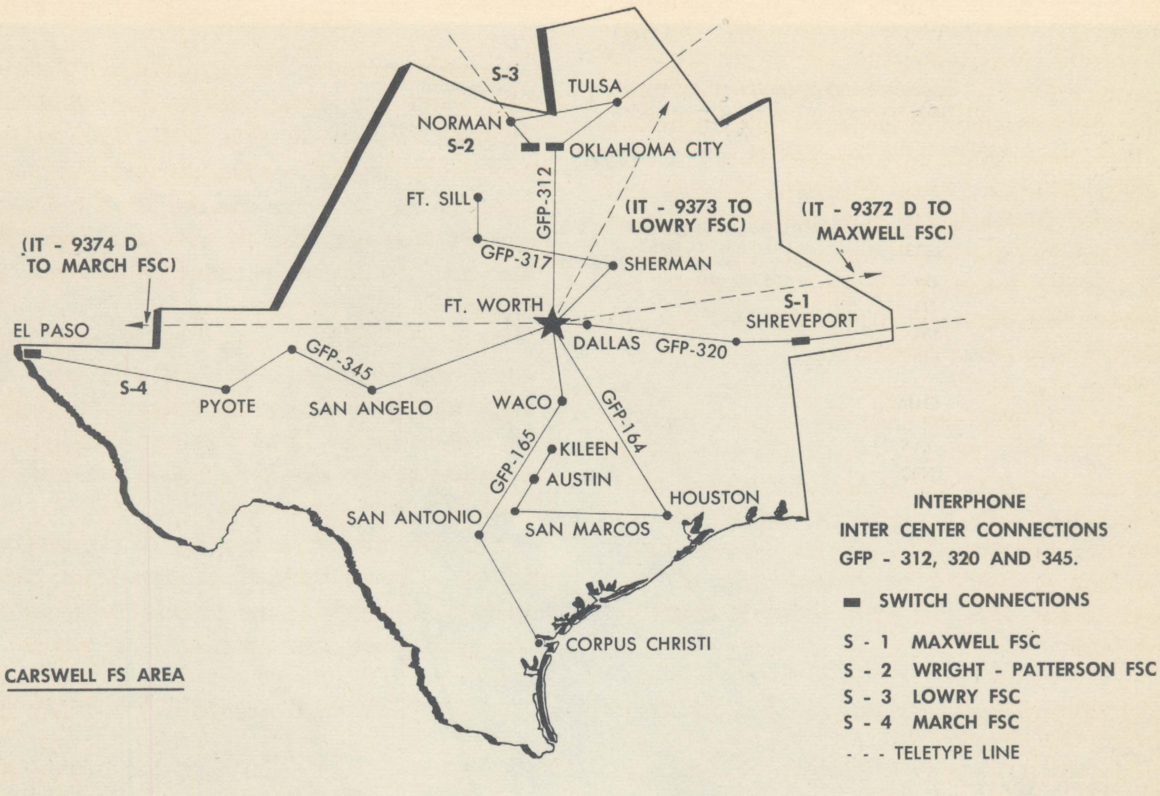
In addition to the Headquarters in Washington, there are eight Flight Service centers located throughout the U.S. The FS area boundaries are set to coincide with the boundaries of the CAA Air Route Traffic Control centers. However, the FS areas are larger than the CAA ARTC areas, as there are several ARTC centers in each FS area.

Each FS center is made up of three units: AACS unit, Weather unit, and a FS unit. The AACS unit provides communications support for the FS center. The Weather unit provides a forecaster and all the facilities available to a pilot in a base operations.

The FS unit is made up of airmen and officers. The airmen act as dispatcher clerks, operate the flight plan boards, and perform the preliminary communications search for



Flight Service Areas.



Communications within Typical Flight Service Area.

overdue aircraft. The FS officers act as operations officers for all nonmilitary bases and for those AF bases for which FS acts as clearing authority. In addition, these officers issue in-flight advisories and act as direction-finding net coordinators for aircraft that are lost or in distress.

SERVICES PROVIDED TO PILOTS BY FLIGHT SERVICE CENTERS

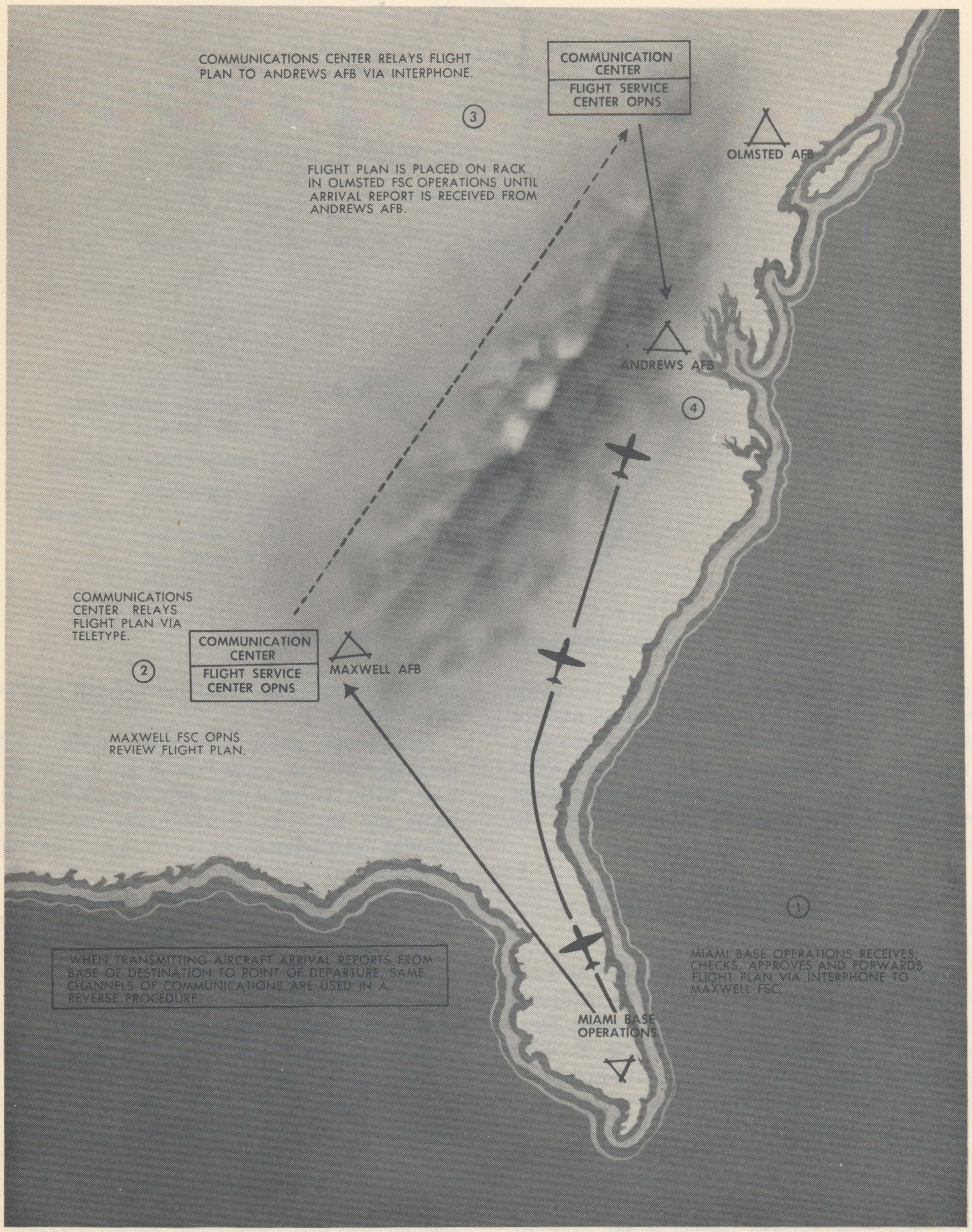
Clearances

One of the major services provided by FS is to act as a central operations office available at all times to you, as a pilot, when local operations facilities are not available. To offer this service, FS centers keep operations officers and weather facilities available 24 hours a day. No matter where you are in the U.S. a FS center is as close as the nearest telephone and is always ready to help you plan your flight.

Here are some general rules on how to use the clearance service provided by each FS center. However, for the *latest information, be sure to consult your Radio Facilities Charts* (AN 08-15-1).

DEPARTURE FROM A MILITARY BASE. FS normally will not clear you from a military base, with the exception of National Guard bases and those bases where the base commander has requested FS to act as his clearing authority.

If you are at a base for which FS is the clearing authority, the airman on duty will call your flight plan in to the FS center over the plan 62 leased telephone line. At the FS center an operations officer will check your flight plan, just as at a base operations, then the weather forecaster will give you an oral briefing on the weather for your flight route. This weather briefing is the same as the weather briefing you would receive in base operations; however, it will be given to you over the telephone. You should ask the same questions you would in base operations, and since it is oral be sure you understand before acknowledging it as an adequate weather briefing.



Schematic Drawing of Communications Net between Miami and Andrews.

If you do not have your own clearing authority, FS will issue an oral approval and give the time this approval is void.

If you have your own clearing authority, FS will merely acknowledge receipt of the flight plan.

DEPARTURE FROM NONMILITARY AIRFIELDS.

"P" Field (CAA Communications Available). If you are departing from a nonmilitary field that is designated as a "P" field in the Radio Facilities Charts, you must file a flight plan with the CAA communications stations for transmission to FS. If you have your own clearing authority, you can take off right away, but if you do not have your own clearing authority, you must wait for FS approval before taking off.

"PC" Field (CAA Communications Not Available). If you have your own clearing authority, you may take off and file your flight plan in the air through the nearest CAA radio station. If you do not have your own clearing authority, you must call FS on the telephone, file your flight plan, and have it approved before you take off.

ARRIVAL REPORTS. Reporting your arrival is just as important as filing a flight plan. As a matter of fact, the flight is not completed until your arrival has been reported.

Landing at Military Field. The tower will normally close your flight plan for you, but it is still your responsibility to see that the arrival report has been filed. You can do this by turning in a copy of the form DD 175 at base operations.

Landing at "P" Field. You must be sure to report your arrival to the CAA communications station (the CAA Radio Station, *NOT* the tower) for transmission to FS.

Landing at "PC" Field. Prior to landing at a "PC" field, contact the nearest CAA radio station and close your flight plan. In case you are unable to contact a CAA radio station, you must close your flight plan with FS by long distance telephone.

NOTE

Do not leave the airfield until you are sure your flight plan has been *closed.*

Communications Search for Overdue Aircraft

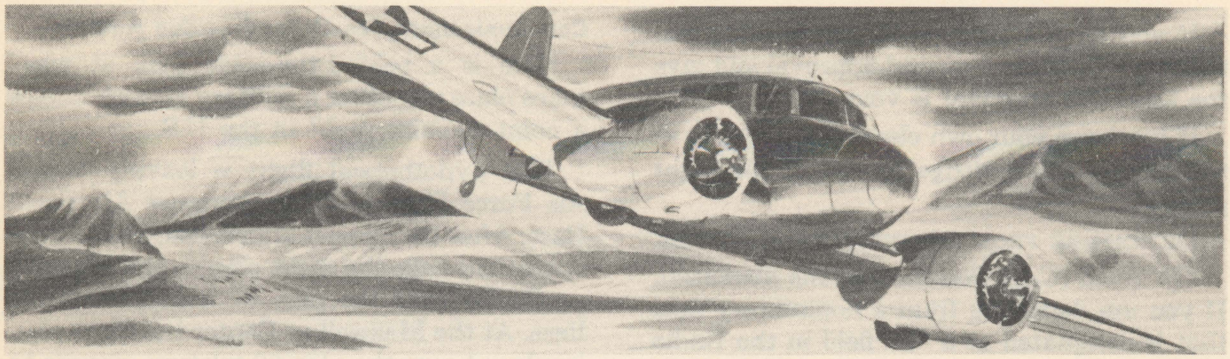
Here is a behind-the-scene look at what takes place whenever a military aircraft makes a point-to-point flight in the U.S.

This hypothetical flight is leaving Miami Air Force Base to go to Andrews Air Force Base. After the aircraft is airborne, Miami base operations calls the flight plan to the Maxwell FS Center over the plan 62 leased telephone lines. At the Maxwell FS Center the flight plan is relayed over the plan 62 teletype circuits to the Olmsted Flight Service Center. Here the flight plan is called to Andrews Air Force Base operations over the plan 62 telephone lines and a copy kept in the FS center.

On the copy that is kept in the FSC, the ETA of the flight is computed, and the flight plan is checked to see whether the route of flight penetrated an Air Defense Identification Zone (ADIZ). In this case the flight does not; however, had the flight penetrated an ADIZ, the time of penetration and expected point of penetration would be forwarded to the Air Defense Command. After this scrutiny, the flight plan is put on the active flight plan file rack in Olmsted FS Center to await an arrival report.

For this flight, assume that the expected arrival time at Andrews Air Force Base is 1430E. If Olmsted FS Center has not received an arrival report on this flight by 1530E, they start a preliminary communications search in an attempt to locate the aircraft. In this search the FS center contacts the base of departure and the destination to request that a ramp check be made. This is done to see whether the aircraft reported on the flight plan has actually departed or if possibly it arrived at Andrews and the arrival report was mislaid. If the aircraft cannot be located at destination or point of departure, the Olmsted FS Center sends out an alert notice (ALNOT) to the FS areas over which the flight may have passed, to CAA, and to the State police. The center also notifies Air Rescue that this aircraft is now considered an overdue aircraft.

FS then calls all the military air bases along the route of flight and sends teletype information requests to all the CAA stations



along the route of flight in an attempt to find out whether the pilot landed en route and failed to close his flight plan. If this search is unsuccessful, the aircraft is presumed to have crashed and Air Rescue starts to search for the aircraft.

In a large number of cases, these extended communications searches are unnecessary, because the pilot decided to land at a field other than his original destination, failed to file a change en route, and then landed and failed to close his flight plan with FS. Such negligence wastes manpower and causes unnecessary use of equipment. For these reasons, always be sure to close your flight plan whenever or wherever you land.

Lost Aircraft or Aircraft in Distress

Even with the finest training in the world and the finest aircraft in the world, you can still get lost or have an in-flight emergency. Should this happen to you, FS is ready and waiting to help you.

If you get lost and can contact any radio facility, have this radio facility advise FS you are lost and need assistance. This is very important, because FS cannot help you unless it knows that you need assistance. On receiving word that you are lost, FS puts special emergency procedures into effect. (The officers in FSC are rated, so they know what in-flight emergencies can mean.) All the Direction Finding (D/F) Stations in the area are alerted and start listening to the frequency you are transmitting on. When lost, remember your best friend is *altitude*. The closer to the ground you are, the fewer D/F stations that can hear you.

When the D/F stations pick you up and start to "work" you, they give FS your bearings. FS plots these bearings on D/F plotting boards. Your position is then relayed back to you, and if necessary, a heading to the nearest field can be given. (FS has handled many thousands of lost aircraft and brought them in safely, so if you should ever get lost, do not hesitate to call for assistance; and, above all, do not wait until you are almost out of fuel before asking for assistance.)

If you should experience in-flight difficulty and need an airport in a hurry, be sure to ask the nearest CAA Range Station, or military airways station for FS assistance. FS can direct you to the nearest airfield that is capable of handling the type aircraft you are flying and, if necessary, have the local fire equipment waiting for you.

In-Flight Advisory Service

Flight Service will issue in-flight advisories *if you (the pilot) request one*, or if a base operations requests one be issued to an aircraft. Normally, pilots request advisories be issued when they are flying into an area of questionable weather and wish to be advised if their destination or alternate goes below minimums. Base operations sometimes requests advisories be issued to inbound aircraft when their station goes to O-O or when some facility such as the GCA unit becomes inoperative. The in-flight advisories issued to pilots are only advisory in nature. The final responsibility is still with the pilot. No ground agency may make any final decision for him in which the safety of the aircraft is in question. The recommendations of Flight Service are conservative and always in the interest of safety.

Additional Services

In addition to the major services provided for the pilot, FS also performs other services which indirectly assist the pilot:

1. Prepares and maintains a Master Hurricane Evacuation Plan and advises potential and evacuating air bases of hurricane conditions that might affect them.

2. Keeps all current NOTAMS and complete information regarding radio aids, size, and conditions of landing fields, availability of servicing facilities, and any other condition which might affect the safety or efficiency of military flying.

3. Disseminates air raid warnings to all military air bases in the continental U.S.

4. Sends lecture teams to air bases to keep pilots informed of the latest flying procedures and regulations.

EXAMPLES OF FLIGHT SERVICE CENTERS IN OPERATION

The following reports of incidents were taken from FS files and should provide a clear perspective of the services available and how they operate in actual practice.

Aircraft in Distress

One night about 2130C the Maxwell Airways Station reported to Flight Service that a B-29 was in distress about 60 miles north of Birmingham, Alabama. An outboard propeller had come off and hit the inboard engine, knocking it out and starting a fire. The pilot was unable to maintain altitude and was preparing to bail out his crew.

Flight Service checked its file of air fields and found there was a civilian field at Gadsden, Alabama, about 20 miles from the pilot's last reported position, which could handle a B-29. FS advised the pilot of this field, and the pilot said he would try to make it to the field.

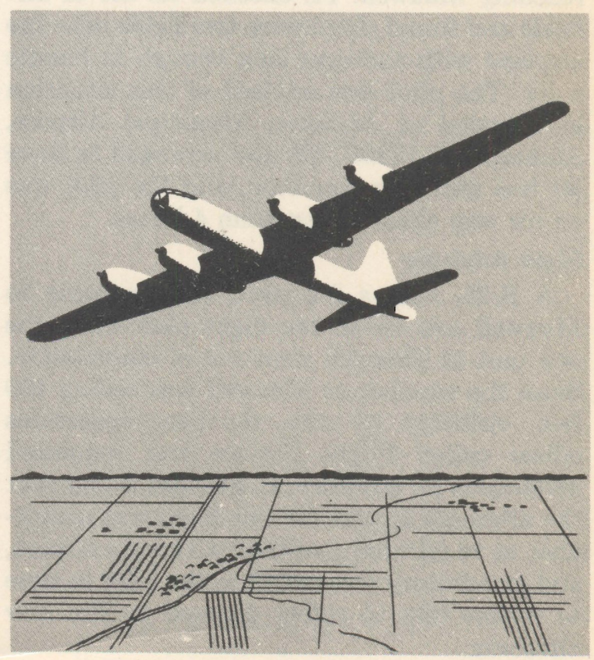
The FS called long distance to Gadsden, Alabama, and alerted the local fire and crash equipment, made sure the lights were on, and asked about the local weather and wind direction. This additional information was relayed to the pilot.

The pilot was able to make the field and with the help of the local fire-fighting equipment extinguished the fire. The pilot's fine technique and Flight Service's help saved the Air Force a $1,000,000 airplane and possible injury to the 11 crew members. Flight Service contacted the nearest Air Force base and arranged for maintenance. Then, when this airplane had been repaired, FS cleared it on to Savannah.

Lost Aircraft

An F-84 left Langley Air Force Base at 1500C on a VFR flight plan to Eglin Air Force Base with the weather en route forecast as scattered thunderstorms. At 1710C, Birmingham tower advised Flight Service that this AF Jet was lost with only 20 minutes' fuel remaining. Flight Service immediately alerted all the D/F Stations in its area. Maxwell Air Force Base D/F and NAS Atlanta D/F advised they could read the airplane and give a class C steer, but the signal strength was very weak. Flight Service used these steers and its D/F board to locate the pilot's approximate position as being at Stevenson, Tennessee.

The pilot advised he could see a lake, and his position was then definitely established. Meanwhile, the pilot had elected to work the Maxwell D/F. Inbound to Maxwell, he reported



only 10 minutes' fuel remaining. FS computed that, from his present position, the airplane would run out of fuel about 35 miles before reaching Maxwell. FS checked its file of airfields and found there were two fields near the airplane with runways long enough to handle a jet. The pilot was advised of this situation and landed at Anniston Municipal Airport, Alabama, at 1730C. FS also arranged to have jet fuel sent into Anniston, and the pilot was on his way again in less than 4 hours.

Flight Advisory

A B-25, with a 3-2 pilot, was en route to Maxwell AFB on an IFR flight plan when the GCA unit at Maxwell went out of commission. Since the weather at Maxwell was ceiling 400 feet, visibility ½ mile, the base operations officer called Flight Service and requested issuance of an advisory. It was also found that the alternate airport for this flight was unsuitable, so FS selected a suitable alternate airport, and an advisory was issued to the pilot in time to enable him to safely proceed to the new alternate.

A C-54 en route to the ZI encountered much higher winds than were forecast and arrived over its destination with less fuel than anticipated. After several unsuccessful passes were made at the destination, the pilot elected to go to his alternate. En route to his alternate, the pilot realized he could not make it, because he had burned much more fuel than he had planned. He requested that FS issue an advisory and find a suitable alternate within the range of his remaining fuel. FS checked all the weather information and the forecasts available and located a suitable civilian field within the C-54's remaining fuel range. The pilot was advised of this new alternate, and the flight was successfully terminated at this airport. (FS had even notified the U.S. Customs and Immigration Service to expect the aircraft.)

NOTE

These services were specifically designed to help the pilot and to make flying safer. Remember, it is your Flight Service. *Use It!*

CHAPTER TWENTY-FOUR

Air Traffic Control

The rapid increase of airways traffic during the late twenties and early thirties made apparent the necessity for controlled separation of traffic during periods of restricted visibility. This was particularly true since all traffic between important terminals tended to follow the same routes. In 1927, the Aeronautical Branch of the Department of Commerce identified and surveyed these routes, and the civil airways were thus initiated. Any discussion of air traffic control must give consideration to the nature of these civil airways.

As the airway mileage increased from 1,200 miles in 1927 to 40,000 miles in 1949, a great expansion occurred in radio facilities that afforded the means by which control of air traffic might be affected. These facilities also encouraged instrument flight and thereby necessitated the formation of an agency specifically authorized to assure aircraft separation during instrument flying weather conditions, and, in effect, to act as the eyes of the instrument pilot with respect to other traffic. Under the present organization of the Air Traffic Control Division of the Civil Aeronautics Administration, two services are furnished, Air Route Traffic Control and Airport Traffic Control. Since these two services overlap they are generally referred to by the single designation, Air Traffic Control, abbreviated ATC.

THE CIVIL AIRWAYS

The civil airways of the United States consist of a well-defined network of aerial highways, and the Air Traffic Control division of CAA is given authority to control the air traffic that is operating within the boundaries of these airways and their intersections and terminal points. These airways are 10 miles wide and extend from the ground surface to all levels above the 10-mile width. All controlled airways are equipped with aids to navigation such as radio ranges, fan-marker beacons, radio homing stations, and z-type marker beacons used to mark the cone of silence over the range stations. In addition, most of the airways are marked with rotating light beacons for night visual flight. There are some airways which are uncontrolled and do not have the above facilities. They are marked differently in the Radio Facilities Charts.

All of the airways are designated by color and number. The airway routes extending east

and west are designated as Green and Red airways, and are further designated by number. For example, the airway extending east and west between Albuquerque, N. M. and Amarillo, Texas is identified as Green 4.

The airway routes extending north and south are designated as Amber and Blue airways, and are also further designated by number. For example, the airway extending north and south between Memphis, Tenn. and New Orleans, La. is identified as Amber 5.

CONTROL OF AIR TRAFFIC BY ATC

ATC was created in 1936 with the specific purpose of expediting the flow of air traffic along the civil airways during defined instrument flight conditions in a manner consistent with safety. This mission of ATC necessitates control, which in turn, is delegated to 26 control centers in the continental United States. Each control center is centrally located with respect to the area over which it has jurisdiction.

Each center controls an average of 2,100 miles of civil airways, and these airways are considered to be in a control area, the name of the control center. For example, all airways in the Fort Worth Air Route Traffic Control area are under the jurisdiction of the Fort Worth Air Route Traffic Control Center.

Each center is coordinated with all of the CAA range stations located on the civil airways, control towers at commercial and military airports, military operations offices, and airlines dispatch offices by means of an interphone communications system. Each center is also coordinated with every other center by the interphone system.

The control of air traffic is dependent upon the use of radio facilities, and in order to establish effective control, the center must be in contact with all air traffic operating within the limits of the controlled areas. The same facilities used for air-ground communications are used for radio navigation, i.e., radio ranges. As a result, radio ranges and marker beacon facilities have become the basis for airways navigation and traffic control; without these, systematic traffic procedures could not have been developed.

OPERATING PROCEDURES OF ATC

The successful operation of ATC depends upon the coordination of the dispatching agency of the aircraft concerned, the control towers concerned, all the CAA radio facilities and the control center.

The significant feature of traffic control by ATC is aircraft separation. This separation is provided in three dimensions, and the control of each dimension may be employed when necessary. The nature of separation in three dimensions is as follows:

1. VERTICAL SEPARATION. *This occurs when the traffic is staggered at different altitudes. For instance, if several aircraft depart simultaneously from an airport with the intent of cruising in the same direction and on the same airway, they will be assigned different altitudes by ATC. The minimum separation employed is 1,000 feet.*
2. LONGITUDINAL SEPARATION. *This type of separation is effected by timing flights so that a ten-minute interval exists between aircraft flying on airways where the fixes are less than 100 miles apart. If the fixes along the airways are more than 100 miles apart, the time interval between the aircraft must be at least 15 minutes. This rule is roughly applied depending upon the situation existing and can be considered as a fairly flexible regulation.*
3. LATERAL SEPARATION. *This type of separation is effected by clearing traffic to fly on the right side of the airway or range leg. When this type of separation is employed, the aircraft are cleared well to the right of the "on-course" of the range leg concerned. This type of separation is employed along with the other types of separation and is rarely employed as the sole type of separation.*

ATC obtains information relevant to a flight on the airways from the clearance agency or dispatch office concerned prior to take-off. An Air Force pilot, contemplating a flight under instrument flight plan rules on or across

civil airways submits the pertinent information on the NME Form 175 (Department of Defense Clearance Form) in Section D to the base operations dispatch section. (See Fig. 46.) The dispatch section, in turn, submits this information by interphone to the appropriate ATC center. The information desired by the ATC center includes the following information in Section D of NME Form 175.

Radio call numbers (last four digits of the aircraft serial number).

Type of aircraft.

Pilot's last name.

Point of departure.

Whether all of the flight is to be conducted according to IFR. If the flight is divided into several portions, and some portions are to be conducted according to VFR and some are to be conducted according to IFR, then the information on the Section D should so indicate.

Altitude (or altitudes) at which the flight will be conducted. Route (or routes) that will be flown. The information should specify all airways by color and number that will be followed during the entire flight.

Destination (Airport of first intended landing).

Estimated true air speed.

Radio transmitting frequencies that will be used.

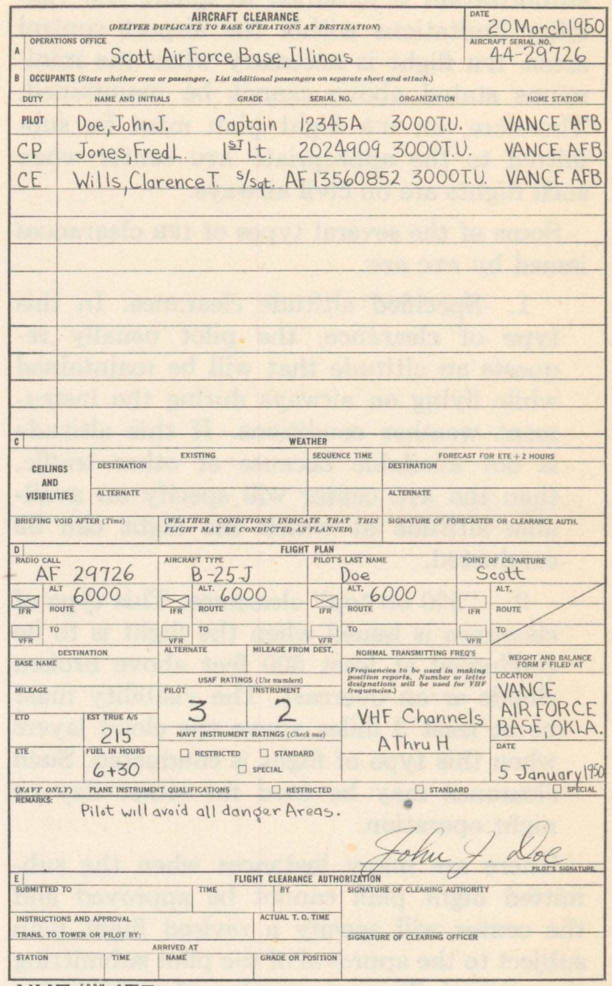
Proposed take-off time.

Estimated time enroute.

Alternate airport.

Hours of fuel aboard the aircraft.

ATC clearance for an IFR flight may be requested prior to take-off or while the aircraft is in the air flying according to VFR. Under no circumstances will the flight be conducted according to IFR until clearance has been obtained from the appropriate ATC center. A delay may be incurred to the flight because of the inability of the center to clear the aircraft concerned and still maintain the proper separation necessary for safety. This delay is due usually to congested traffic conditions


AIRCRAFT CLEARANCE
(DELIVER DUPLICATE TO BASE OPERATIONS AT DESTINATION)
DATE 20 March 1950
A OPERATIONS OFFICE Scott Air Force Base, Illinois
AIRCRAFT SERIAL NO. 44-29726
B OCCUPANTS (State whether crew or passenger. List additional passengers on separate sheet and attach.)

DUTY	NAME AND INITIALS	GRADE	SERIAL NO.	ORGANIZATION	HOME STATION
PILOT	Doe, John J.	Captain	12345A	3000 T.U.	VANCE AFB
CP	Jones, Fred L.	1st Lt.	2024909	3000 T.U.	VANCE AFB
CE	Wills, Clarence T.	S/Sgt.	AF 13560852	3000 T.U.	VANCE AFB

C WEATHER
CEILINGS AND VISIBILITIES — EXISTING: DESTINATION, ALTERNATE — SEQUENCE TIME — FORECAST FOR ETE + 2 HOURS: DESTINATION, ALTERNATE
BRIEFING VOID AFTER (Time) — (WEATHER CONDITIONS INDICATE THAT THIS FLIGHT MAY BE CONDUCTED AS PLANNED) — SIGNATURE OF FORECASTER OR CLEARANCE AUTH.

D FLIGHT PLAN
RADIO CALL AF 29726 — AIRCRAFT TYPE B-25J — PILOT'S LAST NAME Doe — POINT OF DEPARTURE Scott
IFR ALT 6000 ROUTE TO VFR — IFR ALT. 6000 ROUTE TO VFR — IFR ALT. 6000 ROUTE TO VFR — IFR ALT. ROUTE TO VFR
DESTINATION BASE NAME — MILEAGE — ALTERNATE — MILEAGE FROM DEST.
USAF RATINGS (Use numbers) PILOT 3 INSTRUMENT 2
NORMAL TRANSMITTING FREQ'S (Frequencies to be used in making position reports. Number or letter designations will be used for VHF frequencies.) VHF Channels A Thru H
WEIGHT AND BALANCE FORM F FILED AT LOCATION VANCE AIR FORCE BASE, OKLA.
ETD — EST TRUE A/S 215
ETE — FUEL IN HOURS 6+30
NAVY INSTRUMENT RATINGS (Check one) RESTRICTED STANDARD SPECIAL
DATE 5 January 1950
(NAVY ONLY) PLANE INSTRUMENT QUALIFICATIONS RESTRICTED STANDARD SPECIAL
REMARKS: Pilot will avoid all danger Areas.
John J. Doe
PILOT'S SIGNATURE

E FLIGHT CLEARANCE AUTHORIZATION
SUBMITTED TO — TIME — BY — SIGNATURE OF CLEARING AUTHORITY
INSTRUCTIONS AND APPROVAL — ACTUAL T. O. TIME
TRANS. TO TOWER OR PILOT BY: — SIGNATURE OF CLEARING OFFICER
ARRIVED AT: STATION — TIME — NAME — GRADE OR POSITION

NME FORM 1 MAR 49 175

Figure 46—NME—Form 175.

along the proposed flight path.

The type of clearance for the flight will be determined largely by the weather involved. Since ATC is not concerned with VFR flights, this type of clearance is not considered here. The weather minimums for VFR flights should be noted, however, in order to provide a basis for filing flight plans for IFR flights. VFR flight may be conducted when a minimum ceiling of 1,000 feet exists at the point of departure, along the entire route and at the destination. The visibility must be at least 3 miles at the point of departure, en route and at the destination except when specific

authorization is obtained to ignore the visibility limitations within the airport control areas. IFR flight is necessary when the minimums stated above cannot be maintained. Therefore, an IFR flight plan must be submitted to the appropriate ATC center when such flights are on civil airways.

Some of the several types of IFR clearances issued by ATC are:

1. Specified altitude clearance. In this type of clearance, the pilot usually requests an altitude that will be maintained while flying on airways during the instrument weather conditions. If this altitude is not available because of other traffic, then the ATC center will specify an available altitude at which the flight can be conducted.

2. "500 on top" clearance. This type of clearance is issued when the flight is to be conducted at least 500 feet above broken clouds or an overcast. The visibility must be at least 3 miles above the cloud layers when this type of flight is conducted. Such clearance may be used for either day or night operation.

There are many instances when the submitted flight plan cannot be approved and the center will specify a revised flight plan subject to the approval of the pilot submitting the original. This occurs when the ATC center cannot approve the submitted flight plan because of congested traffic conditions or because of aircraft that have been previously assigned to the request altitude specified in the flight plan. If this is the case, the control center recommends another altitude for the flight plan and the pilot can either accept the revised plan or accept a delay in the approval of the proposed flight plan. The flight may be re-routed to eliminate long delays which are a result of the presence of aircraft at all 1,000-foot intervals on the desired airway route. When heavy traffic exists within the clouds, ATC will, when possible, clear later traffic for a "500 on top" flight, since horizontal visual conditions of 3 miles or better reduce the difficulty of traffic separation. Traffic separation is not necessary when aircraft can "see or be seen"—This rule of thumb is one basis of ATC jurisdiction.

THE FLIGHT-FOLLOWING FUNCTION OF THE ATC CENTER

The ATC center follows each flight separately to effect adequate and safe traffic control. When the center obtains the flight plan and approves it, the flight information is immediately posted on a "flight progress board." The flight information necessary for safe and effective control should include the following:

Identification of the flight, e.g., Air Force 4567.

Type of aircraft.

Destination and point of departure.

Estimated time of arrival at the destination.

Time over last radio fix.

As the flight progresses along its intended route, the information is posted on the flight progress board, and the center can thereby maintain an accurate check as to the exact location of all aircraft operating within its area.

Position Reporting

The pilot is required by regulation to give a position report at every designated compulsory reporting point if the flight is being conducted according to IFR. If the ATC center gets no position reports from the aircraft, the flight progress function is rendered ineffective. The information to be included in a position report is as follows:

Identification (last four digits of the aircraft serial number, e.g., Air Force 4567).

Position (position over a radio fix or range station. Definite positions should be used because approximate positions cannot be used to predicate control).

Time (the exact time over the position reported).

Indicated altitude.

Type of flight plan (whether VFR or IFR).

Destination.

Estimated time at next reporting point.

Remarks (any remark the pilot considers necessary for reasons of safety for subsequent flights).

Listening Watch

While en route, the pilot must maintain a constant "listening watch" to the nearest CAA facility for possible information or instructions essential to traffic control. Should the presence of another aircraft at the same altitude in the same vicinity be discovered, the pilot is immediately advised and a change of clearance is recommended. If traffic congestion occurs at any point on the airways, it may be necessary for the pilot to "hold" at a radio fix en route until the congestion has been eliminated. Efficiency of operation and safety are greatly improved when each pilot is able to respond immediately to instructions from the center. Such is the case when let-down and low-approach clearance is available before the aircraft actually reaches the radio facility of the destination.

CONTROL OF INSTRUMENT APPROACHES

The priority of approach clearance depends generally upon the sequence of arrival over the radio facility, except in the event of emergencies or when military necessity dictates otherwise. In the event that other traffic is arriving at the time the aircraft is engaging in the let down and low approach, the traffic is required to hold at a designated radio fix. Normally, ATC requires the aircraft to hold as close to the range station as possible. As soon as possible during the flight, ATC clears the pilot to the leg of the appropriate range station at the altitude to maintain while holding, and gives an "expected approach clearance time." Sufficient information is included so that the holding procedure is positively defined.

STACKING

This is the process of clearing a number of aircraft to hold on a given range station at intervals of 1,000 feet of altitude. (See Fig. 47). The aircraft at the bottom of the stack is cleared for an instrument approach, and all other aircraft holding are instructed to descend 1,000 feet. Instrument low-approach clearances are given to the aircraft at the bottom of the stack only. To permit through traffic over the range stations being employed for holding, a "tunnel" is often devised by skpping two thousand foot intervals in this stack. These two altitudes are left unassigned and are used by passing traffic upon clearance from the center. In the event of a missed approach, the pilot who missed must climb immediately and notify the local controller of the situation. Under normal circumstances, when the fuel supply is sufficient, the aircraft is directed to the top of the stack to await another attempt at the low approach.

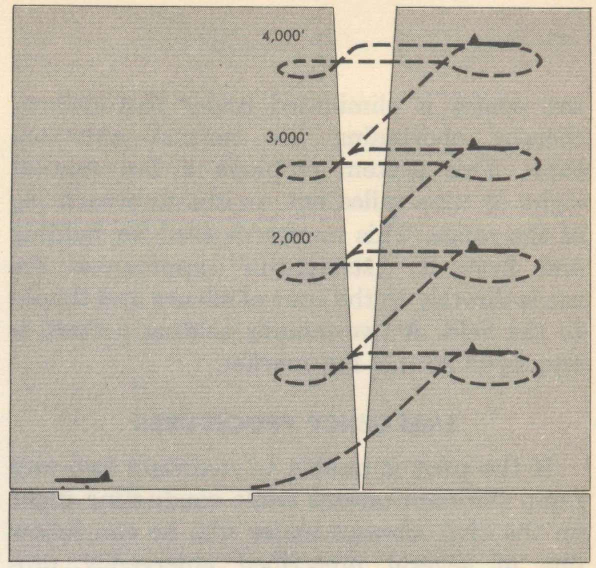


Figure 47. Stacking.

APPROACH CONTROL

The method of controlling instrument low approaches has reduced the time interval between successive approaches to four or seven minutes as compared to an average of ten or fifteen minutes for the conventional method. Approximately forty terminals now employ "approach control procedures." Each approach control terminal is governed by a controller in the control tower who is in a position to take advantage of weather conditions and other low-approach factors that might possibly expedite the flow of traffic into the terminal. The communications lag between the radio range operator and the

ATC center is eliminated under this system, thereby shortening the normal approach time. This system employs a fan marker eight or nine miles out on the approach leg of the range. This marker is used for holding and from it, "straight-in" approaches are made directly to the cone of silence and thence to the field. A two-minute holding pattern is employed at this fan marker.

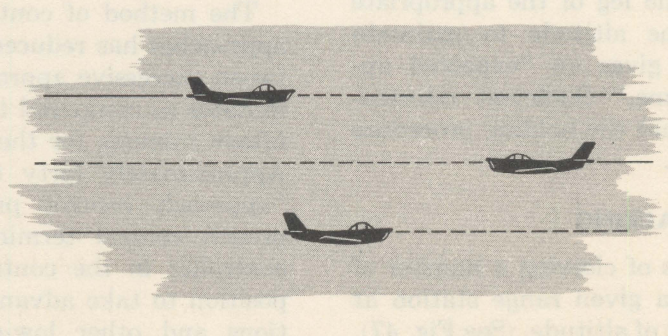
EMERGENCY PROCEDURES

If the pilot is unable to maintain two-way radio communications while conducting flight on the civil airways under IFR, he can follow one of several prescribed emergency procedures. One procedure is to maintain the minimum safe altitude or the last acknowledged assigned altitude, whichever is higher and commence the descent and instrument approach at the destination at the last acknowledged approach time, or if not acknowledged, the estimated time of arrival specified in the flight plan. Another procedure is to land at the nearest airport under visual flight weather conditions and notify ATC.

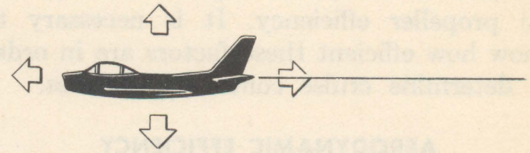
LIMITATIONS OF ATC

The jurisdiction of ATC contains several limitations with which the pilot should be familiar. ATC does not maintain control of IFR traffic that does not follow or cross civil airways; therefore, no separation or control is maintained for any aircraft operating in instrument weather conditions if the flight is conducted off airways. Without this air-ground communication, traffic control is impossible since the basis for traffic control is communication between the aircraft and the center. The center cannot expeditiously control traffic without frequent and accurate position reports from the pilot. The pilot should have these limitations in mind at all times in order to promote safety and efficiency in the coordination between his flight and the control center.

Summary Air Route Traffic Control is charged with the responsibility of expediting the flow of air traffic along the civil airways during instrument weather conditions in a manner consistent with safety. This responsibility necessitates control, which cannot be carried out without the cooperation of all pilots utilizing the facilities of ATC. The instructions a pilot receives from ATC are vital to the safety of the individual pilot, as well as those other pilots who may be flying at that time. Each pilot should be familiar with ATC and its operational procedures so as to realize more vividly the need for over all cooperation. The final point to remember is that ATC cannot authorize deviations from the regulations governing the flight of Air Force aircraft. ATC must not be confused in any manner with Military Flight Service.



CHAPTER TWENTY-FIVE



Cruise Control

This chapter is not a complete coverage of the subject of cruise control, but affiliates cruise control with instrument flying so that it will automatically become a part of flight planning and navigational procedure. Pilots should be familiar with basic factors involved, the sources of operating data, and a standard procedure for solving cruise problems.

The term "cruise control" has caused much confusion among pilots because they visualized a complicated set of curves, graphs, and tabulated data that was difficult for them to understand and which they felt limited them to certain flight conditions on every flight. Actually, cruise control is no more than selecting and following a desired operating condition that is applicable to a particular flight and which gives the most efficient performance of the aircraft. Cruise control has a definite place in everyday flying because it saves fuel and reduces engine wear. Fuel economy is a factor of prime importance to instrument flights because after reaching the destination sufficient fuel must remain to meet requirements for any emergency.

Cruise control is the scientific operation of an aircraft with the primary objective of obtaining the greatest practical efficiency for the type of flight concerned. If the objective of the flight is speed, then the engine should be operated at maximum permissible output in the most efficient manner possible. If the objective of the flight is range, then the aircraft should be operated at power settings and air speeds that will result in maximum range. If the pilot is not concerned with maximum speed or maximum range, then he should operate the aircraft for the most efficient engine output possible at whatever air speed he desires; this increases the fuel reserve at any given point and decreases wear on the engines.

Cruise control procedures can be used for all flights and not just those requiring maximum range. An aircraft should not be operated at the low air speeds for maximum range if the mission does not require maximum range. Efficient operation of the aircraft regardless of the type of flight is good cruise control technique.

CONSIDERATION OF EFFICIENCY

In order to operate an aircraft efficiently, it is necessary to know how efficient the engine, wings, and propeller are. The three fundamental factors that determine the overall efficiency of an aircraft are: (1) aero-

dynamic efficiency, (2) engine efficiency, and (3) propeller efficiency. It is necessary to know how efficient these factors are in order to determine cruise control procedures.

AERODYNAMIC EFFICIENCY

This is essentially the efficiency of the wing and involves several variable factors such as air density, angle of attack, lift and drag. These factors were covered in the chapter titled *Applied Aerodynamics*.

THE FORCES ACTING ON THE AIRFOIL

Air flowing around an airfoil exerts a pressure on each minute portion of the airfoil surface. This pressure is considered positive if it is greater than atmospheric pressure and negative if it is less than atmospheric pressure. These pressures change as the angle of attack is changed. The pressures resulting from the airflow about the airfoil are forces acting on the airfoil.

THE RESULTANT AERODYNAMIC FORCE

The sum of the minute forces acting on the airfoil is called the "resultant aerodynamic force." This resultant acts from a point called the center of pressure which is located at some point along the chord of the wing, usually near the trailing edge. The resultant can be described by giving its magnitude and direction from the point which it acts on the airfoil. The resultant is usually given in terms of its lift and drag components. It varies directly with the air density, the angle of attack, the area of the wing, and the velocity squared. The design of the airfoil affects the resultant and must be considered when determining the magnitude and direction of the resultant.

THE LIFT COMPONENT OF THE RESULTANT AERODYNAMIC FORCE

Lift, a component of the resultant, is perpendicular to the relative wind, and is determined by the same factors that determine the resultant. The factors affecting lift and their relation may be expressed in an equation as follows:

$$Lift = C_L \frac{P}{2} S V^2$$

Lift is expressed in pounds. "CL" is the lift coefficient, "P" the air density expressed in slugs per cu. ft., "S" the wing area expressed in sq. ft., and "V" the velocity of the aircraft in ft. per sec.

The coefficient of lift (C_L) is an absolute numb and has no relation to units of measurement such as feet, pounds, or miles. It is determined by the shape and the angle of attack of the airfoil. Velocity, air density, and wing area have no effect on the lift coefficient. For a given airfoil at a specified angle of attack, the coefficient will have a certain value. As the angle of attack is increased, the lift coefficient increases and as the angle of attack is decreased, the lift coefficient decreases. The value of the lift coefficient is consequently determined by the angle of attack of the airfoil. The values and changes of the lift coefficient, with changes in the angle of attack for a given airfoil, are the characteristics of that airfoil.

THE DRAG COMPONENT OF THE RESULTANT AERODYNAMIC FORCE

Drag, a component of the resultant aerodynamic force, is parallel to the relative wind, and is determined by the same factors that determine the resultant aerodynamic force and also the lift component. Drag is the resistance of the wing to forward motion through the air. The factors affecting drag and their relation may be expressed in an equation as follows:

$$Drag = C_D \frac{P}{2} S V^2$$

In the equation for drag, drag is expressed in pounds, "CD" the drag coefficient, "P" the air density expressed in slugs per cu. ft., "S" the wing area expressed in sq. ft., and "V" the velocity expressed in feet per second. The coefficient of drag (C_D) is also an absolute number having no relation to units of measurement such as pounds, etc. It is determined by the angle of attack and the shape of the airfoil. For a given angle of attack of a specified airfoil, the drag coefficient has a certain value. As the angle of

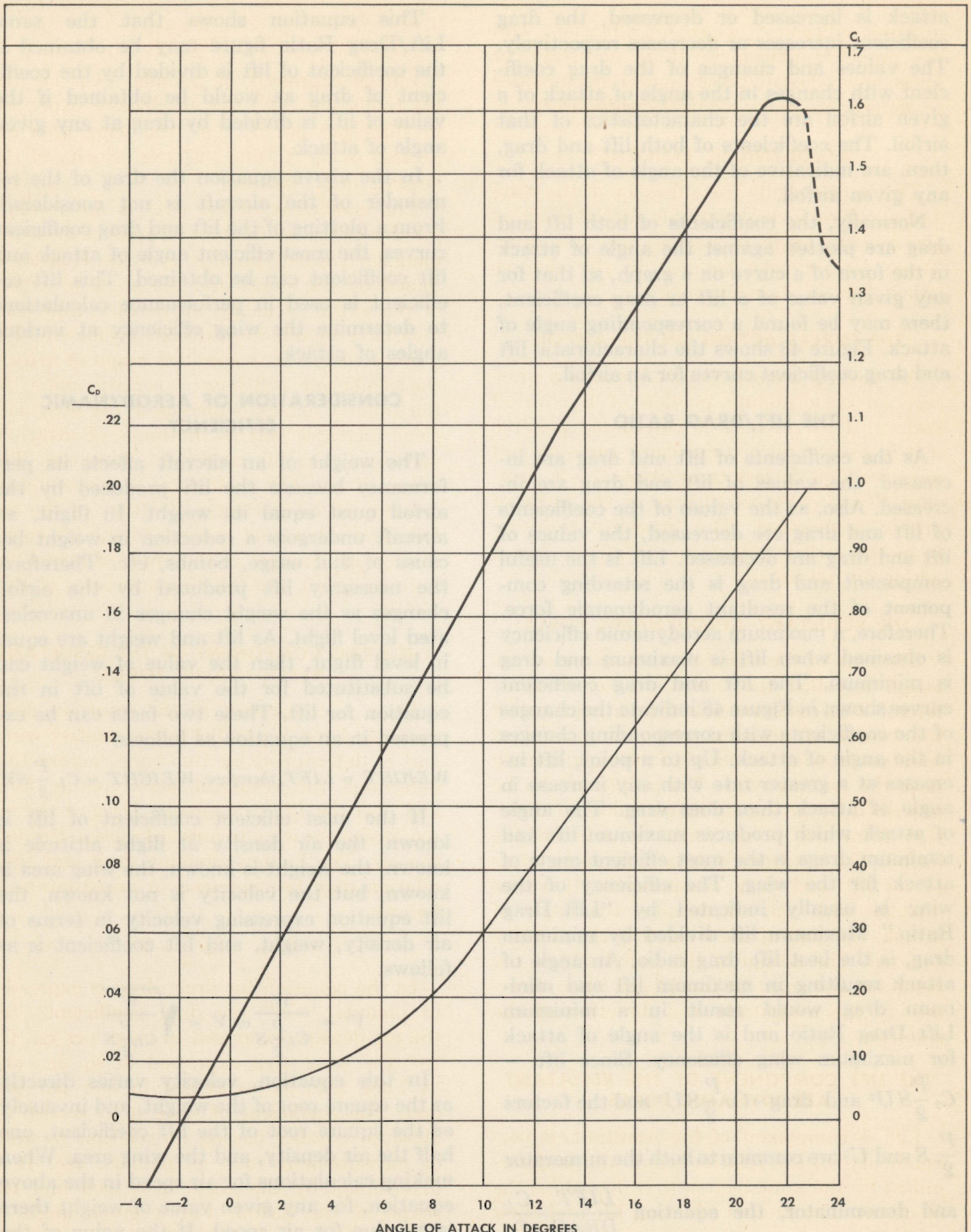


Figure 28. Characteristic lift and drag coefficient curves of an airfoil.

attack is increased or decreased, the drag coefficient increases or decreases respectively. The values and changes of the drag coefficient with changes in the angle of attack of a given airfoil are the characteristics of that airfoil. The coefficients of both lift and drag, then, are indicative of the angle of attack for any given airfoil.

Normally, the coefficients of both lift and drag are plotted against the angle of attack in the form of a curve on a graph, so that for any given value of a lift or drag coefficient, there may be found a corresponding angle of attack. Figure 48 shows the characteristic lift and drag coefficient curves for an airfoil.

THE LIFT/DRAG RATIO

As the coefficients of lift and drag are increased, the values of lift and drag are increased. Also, as the values of the coefficients of lift and drag are decreased, the values of lift and drag are decreased. Lift is the useful component and drag is the retarding component of the resultant aerodynamic force. Therefore, a maximum aerodynamic efficiency is obtained when lift is maximum and drag is minimum. The lift and drag coefficient curves shown in Figure 48 indicate the changes of the coefficients with corresponding changes in the angle of attack. Up to a point, lift increases at a greater rate with any increase in angle of attack than does drag. The angle of attack which produces maximum lift and minimum drags is the most efficient angle of attack for the wing. The efficiency of the wing is usually indicated by "Lift/Drag Ratio." Maximum lift divided by minimum drag, is the best lift/drag radio. An angle of attack resulting in maximum lift and minimum drag would result in a minimum Lift/Drag Ratio and is the angle of attack for maximum wing efficiency. Since lift $= C_2 \frac{P}{2} S\,U^2$ and drag $= Co\,\frac{P}{2} S\,U^2$ and the factors $\frac{P}{2}$, S and U^2 are common to both the numerator and denominator, the equation $\frac{LIFT}{DRAG} = \frac{C_L}{C_D}$ is formed.

This equation shows that the same Lift/Drag Ratio figure may be obtained if the coefficient of lift is divided by the coefficient of drag as would be obtained if the value of lift is divided by drag at any given angle of attack.

In the above equation the drag of the remainder of the aircraft is not considered. From a plotting of the lift and drag coefficient curves, the most efficient angle of attack and lift coefficient can be obtained. This lift coefficient is used in performance calculations to determine the wing efficiency at various angles of attack.

CONSIDERATION OF AERODYNAMIC EFFICIENCY

The weight of an aircraft affects its performance because the lift produced by the airfoil must equal its weight. In flight, an aircraft undergoes a reduction in weight because of fuel usage, bombs, etc. Therefore, the necessary lift produced by the airfoil changes as the weight changes in unaccelerated level flight. As lift and weight are equal in level flight, then the value of weight can be substituted for the value of lift in the equation for lift. These two facts can be expressed in an equation as follows:

$$WEIGHT = LIFT, \textit{ therefore, } WEIGHT = C_L \frac{P}{2} SV^2$$

If the most efficient coefficient of lift is known, the air density at flight altitude is known, the weight is known, the wing area is known, but the velocity is not known, the lift equation expressing velocity in terms of air density, weight, and lift coefficient is as follows:

$$V^2 = \frac{W}{C_L \frac{P}{2} S} \text{ or } V = \sqrt{\frac{W}{C_L \frac{P}{2} S}}$$

In this equation, velocity varies directly as the square root of the weight, and inversely as the square root of the lift coefficient, one half the air density, and the wing area. When making calculations for air speed in the above equation, for any given value of weight there is a value for air speed. If the value of the weight is changed in the equation, then the

value of air speed will change. An increase in weight value results in an increase in air speed value, and, conversely, a decrease in weight value results in a decrease in air speed value. This "air speed-weight" relationship must be maintained to produce maximum aerodynamic efficiency.

The first step in calculating aerodynamic efficiency is to determine the most efficient coefficient of lift from appropriate graphs of the aircraft's airfoil. Then the air density for the flight altitude, the values for gross weight and wing area are substituted in the equation for velocity. The values of wing area, air density, and lift coefficient must remain constant. The weight of the aircraft, therefore, determines the velocity. Since the weight of the aircraft decreases during flight, the air speed must be reduced as the weight decreases if aerodynamic efficiency is maintained. This reduction of air speed as the weight decreases is necessary because less lift is needed to maintain level flight as the weight becomes less. As the angle of attack and lift coefficient must remain constant, and the wing area and the air density are constant, the only way to vary the amount of lift, as the weight varies, is to change the velocity or air speed.

ENGINE EFFICIENCY

Engine efficiency may be placed under several classifications such as, mechanical efficiency, thermal efficiency, volumetric efficiency, and fuel consumption efficiency. However, from a pilot's point of view, which is aircraft performance, fuel consumption efficiency is best when the engine delivers a maximum useful horsepower output with a minimum fuel consumption. This, in turn, requires maximum efficiency of the other classifications of engine efficiency.

INDICATED MEAN EFFECTIVE PRESSURE

This is the pressure developed within the cylinder as a result of combustion. The average of the pressures existing in the cylinder during the power stroke is the indicated mean effective pressure.

INDICATED HORSEPOWER

This is the amount of power developed at the crankshaft. This power, the result of the pressure developed within the cylinder, exerts a force on the piston driving it downward for a distance equal to the stroke, for a given number of times per unit time, multiplied by the number of cylinders.

FRICTION HORSEPOWER

The generators, magnetos, impellors and other accessories of the engine require power for their operation. Power is also needed to overcome friction at the bearings, and superchargers if installed. The power required to operate these accessories is termed Friction Horsepower.

BRAKE HORSEPOWER

This is the amount of useful horsepower that is available at the propeller shaft. A portion of the total indicated horsepower is used as friction horsepower, and the remaining indicated horsepower is the brake horsepower. It is the difference between indicated and friction horsepower.

BRAKE MEAN EFFECTIVE PRESSURE (BMEP)

This is the percentage amount of the total indicated pressure developed within the cylinder that is used to develop brake horsepower. Of the total pressure developed within the cylinder, a portion is used for developing the power to drive the accessories and overcome friction at the bearings (i.e., friction horsepower), and that portion of the indicated pressure remaining is used for developing the brake horsepower, and therefore called brake mean effective pressure.

OPERATING PRINCIPLES OF RECIPROCATING ENGINES

Indicated horsepower is produced by the combustible mixture of fuel and air within the cylinder. The ignition of this mixture causes a rapid increase in the temperature and pressure of the gases in the cylinder. The expanding gases cause high pressures to build up within the combustion chamber.

This pressure on the piston moves it downward on its power stroke. The average of the pressures existing in the cylinder during the power stroke is the indicated mean effective pressure. This average pressure, if exerted on the top of the piston for the duration of the entire power stroke, would produce the total indicated horsepower output of the cylinder. The horsepower produced by the cylinder can be determined in the following manner: The average pressure (IMEP), in psi, acts on a piston, whose area is in square inches, to produce a force, expressed in pounds, equal to the product of the pressure times the area. This force acts through a distance, expressed in units of feet, equal to the length of the stroke to produce work, expressed in foot pounds. This work, when done per unit of time (number of power strokes), equals the power output. Since one horsepower equals 33,000 foot-pounds per minute, results in horsepower output, and in this case, would be indicated horsepower.

The indicated horsepower is transmitted from the cylinder assembly to the crankshaft and then to the propeller shaft where it is converted to useful power. The power that finally reaches the engine propeller shaft is called brake horsepower. The brake horsepower is less than indicated horsepower since a portion of the power developed in the cylinder is consumed in overcoming friction at the bearings, driving the accessories, etc. The power which is absorbed in the engine is called friction horsepower and is the difference between indicated and brake horsepower. An expression of brake horsepower in terms of its components is as follows:

$$\frac{BMEP \times Piston\ Area \times Length\ Stroke \times 1/2\ RPM \times No.\ of\ Cylinders}{33{,}000\ ft\ lb/min} = BHP$$

An expression of indicated horsepower in terms of brake and friction horsepower is as follows:

$$IHP = FHP + BHP, \text{ or } BHP = IHP - FHP$$

For any engine, the variables of the equation for BHP is the pressures developed in the cylinder and the rpm of the engine. As the BMEP is the percentage of the total pressure used to develop horsepower, the factors affecting the total indicated pressure will affect the brake pressure.

FACTORS AFFECTING BRAKE MEAN EFFECTIVE PRESSURE

Two factors which affect the total and brake mean effective pressures are the manifold pressure and the fuel-air ratio. The mixture of fuel and air can vary from .05 lb. of fuel per pound of air to .18 lb. of fuel per pound of air. The best mixture is approximately .08 lb. of fuel per pound of air. Maximum power is developed at this fuel-air ratio. If the manifold pressure is increased, the brake pressure will increase and conversely, if the manifold pressure is decreased, the brake pressure will decrease.

SIGNIFICANCE OF "IHP = FHP + BHP"

In this expression, for a given value of indicated horsepower, brake horsepower will be greatest when friction horsepower is least. Friction horsepower is directly proportional to engine speed (rpm) because as the engine speed increases, the friction at the bearings becomes greater and consequently the power required to overcome this friction becomes greater. The desired brake horsepower should be developed at the lowest possible rpm consistent with engine limitations.

FACTORS AFFECTING FUEL CONSUMPTION

The fuel consumption of the engine is affected, by the fuel-air ratio, the manifold pressure, and the engine rpm. The brake horsepower can be increased or decreased by increasing or decreasing respectively any or all of these three factors. The fuel consumption is also increased or decreased by increasing or decreasing respectively these three factors. The fuel consumption changes at a greater rate in proportion to the change in horsepower output if the engine rpm is used to effect the change in horsepower. Therefore, if maximum useful horsepower output for minimum fuel consumption is desired, then this horsepower must be developed at the lowest efficient engine rpm.

MAXIMUM ENGINE EFFICIENCY

The best engine efficiency is maximum brake horsepower output with a minimum of fuel consumption. This is done by operating the engine at the highest allowable manifold pressure, with the lowest allowable engine rpm, at the best fuel-air ratio.

PROPELLER EFFICIENCY

Thrust horsepower is converted from brake horsepower by means of the propeller. If the propeller could convert all of the brake horsepower to thrust horsepower, it would be 100 per cent efficient. However, the maximum percentage of brake horsepower that can be converted to thrust horsepower is approximately 90 per cent, and it is possible to lose 50 per cent of the brake horsepower into torque and noise.

Propeller efficiency is closely related to aerodynamic efficiency because the propeller blades are airfoils. A propeller blade has a typical airfoil resultant action from the angle of attack and the relative wind. The lift as produced by the blade is perpendicular to the plane of rotation and is called thrust. The drag produced by the blade is parallel to the plane or rotation and is called torque. The torque is the drag which the engine must overcome to rotate the propeller.

The relative wind for a section of a propeller blade is the relation of the air and the movement of that blade section. The direction of movement of the blade section is a resultant of the forward velocity of the aircraft and the velocity and movement of the blade section in its plane of rotation. This resulting velocity of the blade section is helical or slanting with respect to the plane of rotation and is similar to the threads of a screw. The velocity of the blade section is illustrated in Figure 49. In Figure 49, "v_r," is the rotational velocity and can be determined by the number of revolutions per minute times the circumference of the circumscribed circle. "V" is the forward velocity of the aircraft and is the speed of

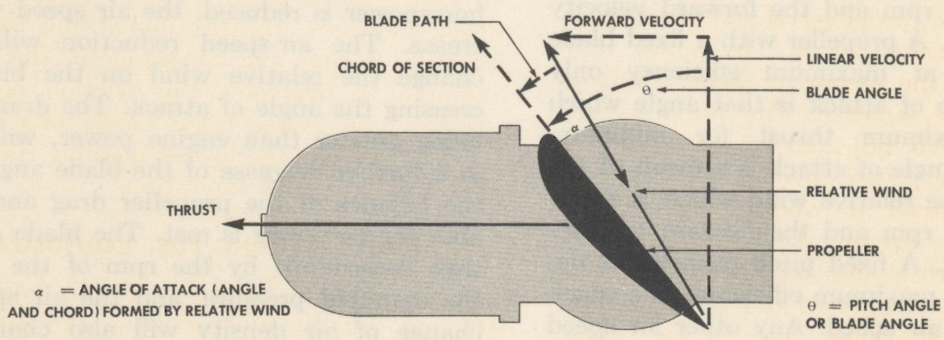
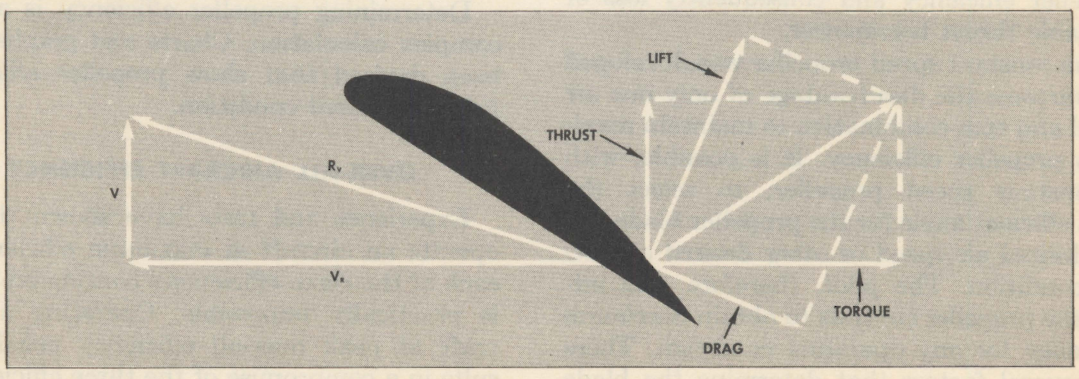


Figure 49. Propeller factors.



Cross-sectional diagram of a propeller blade.

the aircraft expressed in feet per second. The resultant of these two velocities is "R_V". This is the velocity or flight path of that particular blade section. As previously stated, the relative wind is parallel and opposite to the flight path, and the angle of attack is the angle between the chord line of the blade section and the relative wind. Since the section is an airfoil in shape, its maximum efficient operating condition would be at that angle of attack producing maximum thrust for minimum torque.

If the forward velocity is increased and the rotating velocity remains the same, then the velocity or direction of motion of the blade section changes. The relative wind is parallel and opposite to the velocity of the blade section, therefore, whenever the velocity is changed, the relative wind changes. If, in Figure 49, the angle of attack is the most efficient and the forward velocity is reduced, then the relative wind will change which produces a change in the angle of attack, thus reducing efficiency. The maximum efficiency of a fixed pitch propeller will be determined by the engine rpm and the forward velocity of the aircraft. A propeller with a fixed blade will operate at maximum efficiency only when its angle of attack is that angle which produces maximum thrust for minimum torque. This angle of attack is a result of the direction of the relative wind which is determined by the rpm and the forward velocity of the aircraft. A fixed pitch propeller is designed to give maximum efficiency at a specified rpm and air speed. Any other air speed and rpm combination will result in a loss of propeller efficiency and consequently loss of available thrust horsepower.

The constant speed propeller was developed to overcome the disadvantage of only one air speed and rpm combination to maintain maximum propeller efficiency. It is possible, with a constant speed propeller, to select the most efficient angle for the propeller blade, for the desired air speed or other desired operating condition. The pilot, therefore, can adjust the propeller controls to obtain maximum efficiency for any operating condition. There are several factors that determine the blade angle of the propeller and unless they are known and controlled by the pilot a loss in propeller efficiency may result. Some of the factors that determine the blade angle of the propeller are manifold pressure, engine rpm, air speed, and air density.

As stated previously, the propeller produces drag as it is rotated, and the engine produces a force that overcomes the propeller drag in order to rotate the propeller. In order for a constant speed propeller to maintain a constant rpm, the engine torque must equal the propeller drag or torque. If an aircraft equipped with a constant speed propeller is cruising at a given air speed, the power is set at an rpm and manifold pressure. Assuming the air density is constant, the blade angle of the propeller will be such that will satisfy these conditions. If the rpm is reduced and the manifold pressure is kept at the original value, the horsepower produced by the engine will be less. The drag of the propeller blades will now be greater than the power from the engine. In this condition, the blade will decrease its pitch or blade angle, and as the horsepower is reduced, the air speed will decrease. The air-speed reduction will again change the relative wind on the blade increasing the angle of attack. The drag, again being greater than engine power, will result in a further decrease of the blade angle until the balance of the propeller drag and available engine power is met. The blade angle is thus determined by the rpm of the engine, the manifold pressure, and the air speed. A change of air density will also change the blade angle.

Determining propeller efficiency is a very complex calculation. Charts and graphs have been devised that show propeller efficiency for any desired condition.

OVER-ALL AIRCRAFT EFFICIENCY

Experience and tests have shown that to operate an aircraft at maximum efficiency at each of the three efficiencies considered herein is practically impossible. Operating an aircraft at peak over-all efficiency usually results in a compromise of the three efficiencies.

Multiple charts are provided to give accurate data for operation at different gross weights, different external loads, operation on single engine or emergency operation with less than the required number of engines operating. Extreme caution should be used to assure the selection of the chart applicable to the specific operating condition.

USE OF FLIGHT OPERATION INSTRUCTION CHARTS

The following information is a sample cruise problem for a TB-25 aircraft on a no-wind condition flight. Reference is made to Figure 51, 52, 53, and 54. Charts in tabular form for other type aircraft may be used in a similar manner when solving cruise problems for those aircraft. There will be slight variances in the manner of solving for different types of aircraft, however, these variances will be apparent to the pilot who understands cruise control fundamentals.

The conditions and facts relative to the proposed flight are as follows:

Type of aircraft	*TB-25*
Distance to be Flown	*1100 miles*
Flight Altitude	*5000 ft. MSL*
Gross Weight Prior to Take-Off	*26,000 lbs.*
Fuel on Board (Wing Tanks)	*974 gal.*
Airport Elevation	*Sea Level*

The estimated fuel requirements for a take-off at sea level and a climb to 5000 ft. are found on the Take-off, Climb and Landing Chart (Fig. 50). Under the "Climb Data" information, opposite 26,000 lbs. gross weight, the fuel used for take-off at sea level is 70 gallons. This 70 gallons includes fuel used for starting, engine runup, taxiing, normal take-off delay and the take-oft. Under the sub-column "At 5000 ft.", the fuel requirements for starting, taxiing, take-off, etc., *and* the climb to 5000 ft. at 26,000 lbs. gross weight will be 90 gallons. The best indicated air speed is shown as 155 mph and the time for the climb appears as 3 minutes. The distance covered in the climb at 155 mph for 3 minutes is 8 miles. The weight of fuel being approximately 6 lbs. per gallon, the weight of the fuel used for take-off and climb to 5000 ft. is 540 lbs. The gross weight of the aircraft at the point of level-off is, therefore, 25,460 lbs. The fuel remaining is 884 gallons (974-90).

The next step in solving this cruise problem is the determination of the amount of fuel available for cruising. The gross weight of the aircraft at the top of the climb is 25,460 lbs.; therefore, the chart, having as its weight limits, "27,000 lbs. to 24,000 lbs.", will be used. The fuel reserve at destination for the flight will be one hour of fuel necessary for cruising at 5000 ft. at maximum range power settings at the probable gross weight of the aircraft upon arrival over the destination. To obtain this, the amount of fuel reserve will be found on the "24,000 lbs. or less," chart in Column V. At 5000 ft., the fuel used in one hour will be 80 gallons. In general practice, 80 gallons of fuel is considered as being trapped in the tanks and cannot be used. Therefore, the amount of fuel available for cruising will be 884 gallons minus the 80 gallon reserve and the 80 gallons of unusable fuel, which is 724 gallons.

The next step is to determine the column that will be used for computations. For this problem, Column IV shows that 700 gallons will result in 1185 statute miles range, and as the available fuel for cruising is 724 gallons and the distance to be flown is 1092 miles, Column IV is adequate for this problem.

In Column IV at 5000 ft., the figures shown, which will set up the flight condition, are as follows: rpm—1900, Manifold Pressure—28 inches. Mixture—Cruising Lean, Fuel Consumption—135 GPH, True Air Speed—226 MPH. Previously, facts have been shown that indicate that the weight of the aircraft decreases as fuel is used, and that this weight reduction should be considered in the computations. In this problem, the next lower chart for weight limits should be used when the weight falls below 24,000 lbs. The difference between 25,460 lbs. and 24,000 lbs. is 1460 lbs. The weight reduction will be determined by fuel consumption; therefore, when 1460 lbs. of fuel have been used, the computations should then incorporate the "24,000 lbs. or less" chart. The 1460 lbs. of fuel equaled

244 gallons approximately and this 244 gallons is to be consumed at the rate of 135 gph. The power settings should be held for one hour and 45 minutes (244 gallons consumed at the rate of 135 GPH). The distance flown during this first cruise condition is 410 miles (226 mph for one hour and 45 min). The total distance flown at this time is 418 miles and the remaining distance is 682 miles.

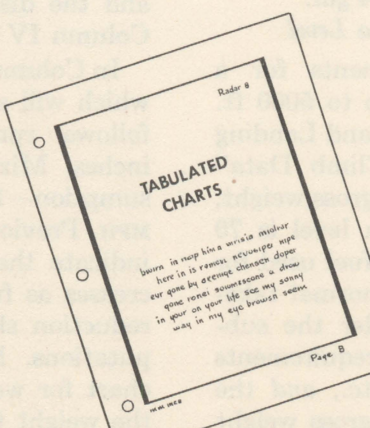
The "24,000 lbs. or less" chart is the minimum weight consideration for two engine operation; therefore, conditions for the remainder of the flight will be computed on that chart. The figures in Column IV opposite 5000 ft. on this chart show the following: RPM—1700, Manifold Pressure—29 inches, Mixture—Cruising Lean, Fuel Consumption—120 GPH, True Air Speed—217 MPH. The amount of time required to fly the remaining distance (682 miles) at 217 MPH is 3 hours and 8 minutes. The amount of fuel used at 120 GPH for 3 hours and 8 minutes is 376 gallons.

The fuel remaining at the destination is the 974 gallons minus 90 gallons for take-off and climb, 244 gallons for the first cruise condition, and 376 gallons for the second cruise condition, and is in this problem, 264 gallons. Of the 264 gallons remaining, 80 gallons are unusable; therefore, 184 gallons (264 gal minus 80 gal) of fuel are available as reserve at the destination.

In summary, knowledge of the maximum range and endurance power settings can be of great value to the pilot under many conditions. The pilot should have maximum range power settings and procedures readily available when adverse winds are encountered, or when a longer distance than was originally anticipated is necessary to effect a safe landing. This, in turn, insures a greater margin of safety. When it is necessary to hold on a range leg waiting for an instrument letdown clearance, or when holding above a station waiting for temporarily unfavorable weather conditions to improve, the pilot should know and use maximum endurance power settings so as to have a greater margin of safety regarding fuel reserves. If the fundamentals and procedures set forth here are incorporated into flight plans, there should be fewer aircraft crashing as a result of lack of fuel.

NOTE

Tabulated charts included in this chapter are extracts of Technical Order AN 01-60GE-1, revised 17 November 1947.



CHAPTER TWENTY-SIX

Principles of Radar

In aviation's early and less active era, air navigation was accomplished almost entirely by dead reckoning from one known point to another. Later, determination of the flight path became possible by following a series of fixed radio beams or in some cases, progressing from point to point by use of directional finding devices. Air traffic control depends largely upon the accuracy of pilot-reported aircraft positions and a time and altitude separation. Successful large-scale air operations, however, require development of a means of determining aircraft position and flight track from take-off to touch-down over any distance, reporting fixed or moving obstacles which would interrupt or impede flight, and providing direction-finding and communications facilities for rescue operations in the event of flight failure. In addition, heavy traffic demands provisions for ground monitoring of all flights as a primary or standby means of accomplishing any of the preceding functions, and for permitting the scheduling of flights with reference to traffic and capacity of landing facilities. Many electronic devices of the future will provide the services outlined above; undoubtedly, one of these will be a system utilizing pulsed radio signals, commonly known as radar.

Although the use of radar in aerial navigation and traffic control is only in its infancy, it is essential that the pilot be fully acquainted with its principles and understand the part it will play as a tool of his trade.

PRINCIPLES OF RADAR

The basic principle of radar may be stated in a single word — reflection. An echo is a simple demonstration of the reflection of sound waves; a noise is produced and radiated in all directions; it strikes a reflecting surface and is returned to its source. The time lag between the original sound and its echo is directly proportional to the distance the sound must travel in its reflecting course. The decrease in intensity of sound waves traveling through air is tremendous; however, weather conditions alter the movement of sound through air; and a crosswind of sufficient force can completely shift the direction of travel of a soundwave.

Radio waves possess some requisites which are lacking in sound waves. A certain frequency band just be used for its excellent

reflective characteristic. Very short radio waves of ultra-high or super-high frequency travel in essentially a straight line and are easily reflected from objects; whereas longer radio waves are not as easily reflected. They continue around the objects and tend to follow the curvature of the earth.

A very short radio wave is produced and sent out in a certain direction in the form of a short pulse lasting from one-half to several micro-seconds (millionths of a second). When this pulse strikes a reflecting surface, some of the reflected waves return to the point of origin where the energy is picked up by a receiver. Inasmuch as the velocity of radio waves is known quite accurately, all that is needed to calculate the round-trip time or distance is some sort of a "super stop-watch" to time the interval between the transmission of the pulse of radio energy into space and the return of the "echo," as it is commonly called. By dividing the time interval by the velocity of the radio waves and then dividing the quotient obtained by two, the distance to the reflecting object can be obtained.

The most convenient means of timing the return of the echo is by the use of a cathode-ray tube. By using a voltage of the required characteristics on the horizontal deflecting plates of the tube, the movement of the spot across the face of the tube produces an apparent horizontal line. The entire length of the line is representative of the total range of the radar set. As the pulse is transmitted, a small portion of the energy is shunted to the vertical deflecting plates of the cathode tube, thus producing a deviation from the straight line in the form of a peak or "pip," as it is usually called. Upon the return of the echo, another portion of electrical energy reaches the vertical plates, producing another pip. Therefore, the distance between the first pip and the echo pip is representative of twice the distance to the reflecting object. The face of the cathode tube is usually calibrated in the units of distance desired.

As soon as the pulse of radio energy leaves the antenna, it is indicated on the cathode-tube screen as the main pulse, and when an echo returns, it is indicated further along the time baseline by a smaller pip.

Several types of cathode-ray tube indicators are used to display the desired distance and direction information. The indicator shown in Figure 55 is known as an "A" scope. Another similar type is the PPI, or Plan Position Indicator, as shown in Figure 56. In the PPI-scope, the time baseline trace starts at the center of the screen and moves outward to the edge. When it reaches the edge, the spot returns almost instantaneously to the starting point and repeats the trace from the center to the edge. Since this tube is designed to show direction as well as range, the complete time baseline is rotated clockwise using the center of the screen as the pivotal point. The rotation of the baseline coincides directly with the rotation of the radar antenna. Echoes of radio energy are made to increase the intensity of the spot on the screen. The rotation of the time baseline in synchronism with the rotation of the radiated radar beam and the retentive qualities of the indicator screen serve to form a polar map of the region around the

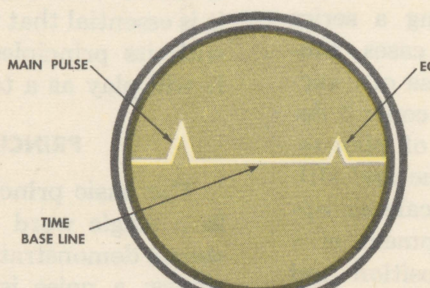


Figure 55—"A" Scope Indicator.

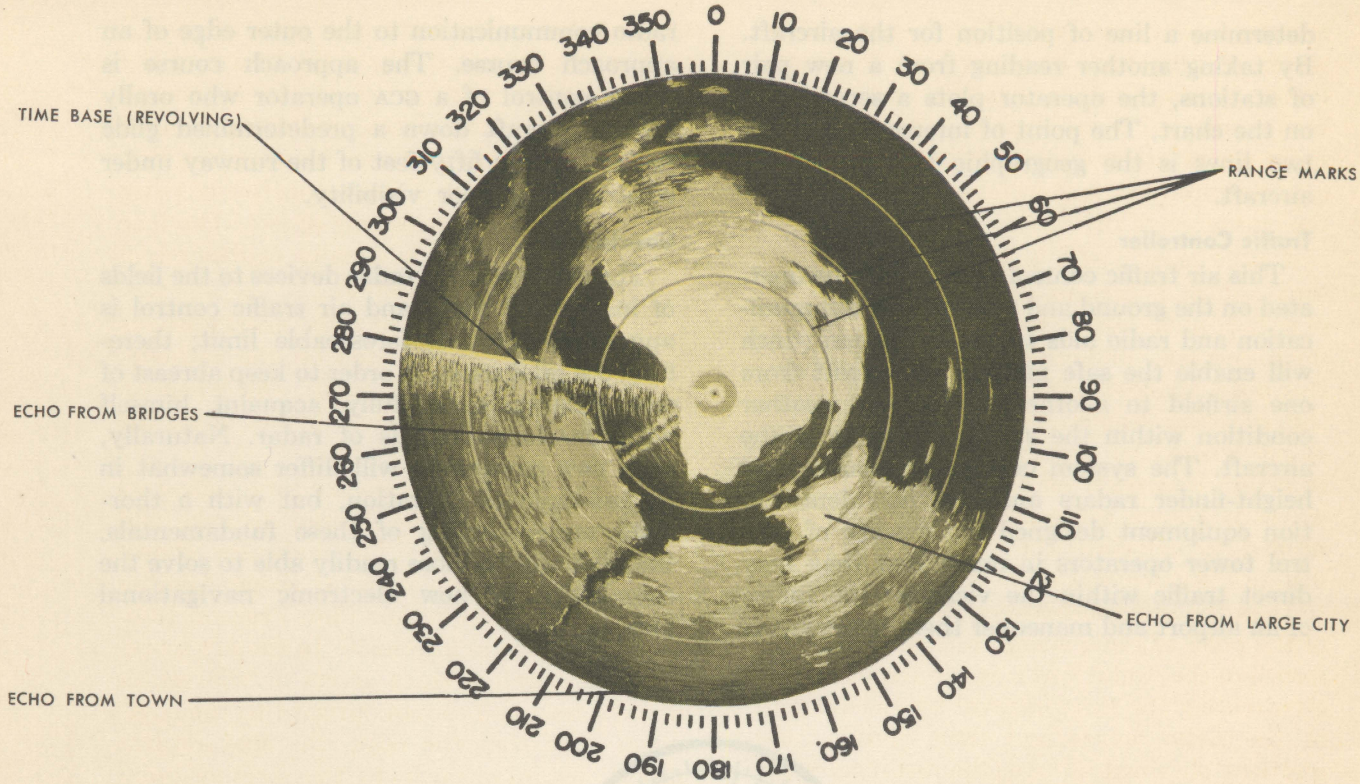


Figure 56—Plan Position Indicator (PPI).

radar installation with the antenna located in its center.

APPLICATION OF RADAR DEVICES TO INSTRUMENT FLIGHT

Shoran

Shoran is a radar system which provides a high degree of precision. A pulse radio signal transmitted from the airborne equipment triggers two ground stations which are separated by a known distance. By measuring the elapsed time between the transmittal and subsequent reception of the return signal from the ground stations, the equipment determines the distance the aircraft is from each station. This provides an exact fix on the position of the aircraft.

Distance Measuring Equipment (DME)

This system consists of an airborne interrogator-responsor indicator and a ground radar beacon for use in facilitating airway navigation and traffic control, airport traffic control, and instrument landing. The airborne component of DME transmits a pulse or pair of pulses which trigger the ground beacon, providing it is within the coverage of the airborne set. The reply from the ground beacon is received and electronically converted into a distance indication by the airborne set. Thus, the pilot is provided with a continuous visual indication of the distance from the selected station.

Loran

This long range aerial navigation system is used primarily over water and is comparable in accuracy to celestial navigation up to 1,200 miles from the baseline of the transmitters. The airborne set receives radio signals from special shore-based loran stations operating in the 1750- to 2000-kilocycle region and measures the difference in time required for the signals from two different stations to reach the aircraft. This datum is plotted on a loran chart which shows time-lag lines for various pairs of stations, making it possible to

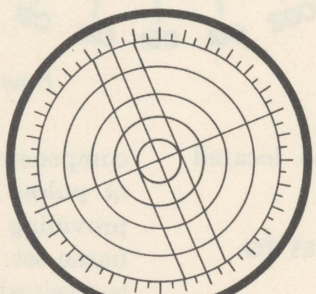
determine a line of position for the aircraft. By taking another reading from a new pair of stations, the operator plots a second LOP on the chart. The point of intersection of the two lines is the geographic location of the aircraft.

Traffic Controller

This air traffic control system is to be operated on the ground and will provide communication and radio aids to air navigation which will enable the safe piloting of aircraft from one airfield to another, under any weather condition within the structural limits of the aircraft. The system consists of search- and height-finder radars and positive identification equipment designed for the use of control tower operators in order that they may direct traffic within the vicinity (100 miles) of an airport and maneuver them by means of radio communication to the outer edge of an approach course. The approach course is under control of a GCA operator who orally directs aircraft down a predetermined glide path to within fifty feet of the runway under conditions of poor visibility.

Conclusion

The application of radar devices to the fields of instrument flight and air traffic control is apparently without foreseeable limit; therefore, the pilot must, in order to keep abreast of new developments, fully acquaint himself with the fundamentals of radar. Naturally, each new equipment will differ somewhat in its principle of operation, but with a thorough understanding of these fundamentals, the pilot will be more readily able to solve the complexity of new electronic navigational aids.



CHAPTER TWENTY-SEVEN

VHF Omnirange

In the past decade air traffic in the United States has increased to such a degree that instrument navigation and traffic control have posed a problem that is uppermost in the minds of virtually all aviation experts. This problem stems from the admitted inadequacies of the present airways system and its associated antiquated radio ranges and communications facilities.

To solve this problem a far-sighted, well-organized program is well underway. The nucleus of this program is the VOR (VHF Omnirange), which will be discussed in this chapter. Other components of the program are DME (Distance Measuring Equipment) and the Offset Course Computer. Both of these are still in the experimental stages of development and will not be included in this discussion.

The VOR is a navigational aid that will eliminate, to a great extent, the deficiencies most prominent in the present-day low-frequency four-course radio ranges. Static due to atmospheric disturbances, multiple courses in mountainous areas, and the limited number of courses available, are the most outstanding deficiencies.

The VOR is a VHF facility which eliminates the first two deficiencies and enables the pilot and the traffic controller to avail themselves of any of 360 courses TO or FROM a range station.

As VOR will, in the very near future, be our primary radio navigational aid, it is paramount that all pilots be conversant with all aspects of its operation and use.

The Omnirange is designed to operate within the 112-118 mc band and has a power output of approximately 200 watts. It produces an infinite number of courses emanating from the transmitter antenna array like the spokes from the hub of a wheel. These courses are known as radials and are identified by their magnetic direction *from* the station. The equipment is VHF, subject to line-of-sight restriction and its range varies proportionally to the altitude of the receiving equipment. Therefore, obstruction free installation sites are necessary for the most advantageous and dependable utilization of the VOR.

PRINCIPLES OF OPERATION OF VOR TRANSMITTERS

The transmission principle of the omnirange is based on the creation of a phase

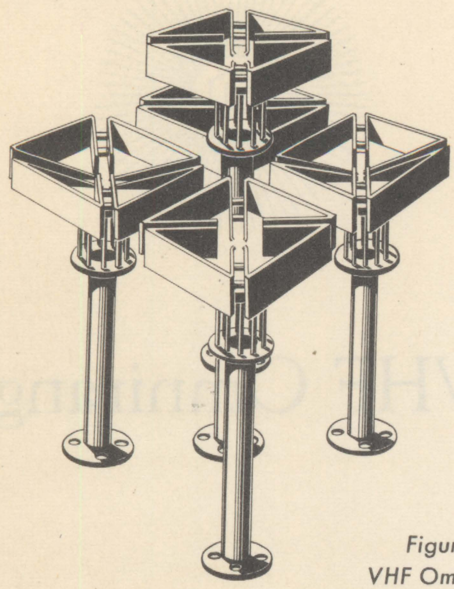


Figure 57—VHF Omnirange Antenna System

difference between two radiated audio frequency signals. Magnetic north is used as the base line for measuring the phase relationship. Of the two signals transmitted one is nondirectional and has a constant phase throughout its 360 degrees of azimuth. It is the REFERENCE phase and is radiated from the center antenna of a five element group. (See Figure 57.) The second signal is a rotating signal with a speed of 1800 rpm. It is called the VARIABLE phase and is radiated from 4 stationary antennas, which are connected in pairs to a motor driven goniometer. As the goniometer revolves, the RF voltage fed to each pair of antennae varies sinusoidally at the rate of 30 cps to produce the rotating field.

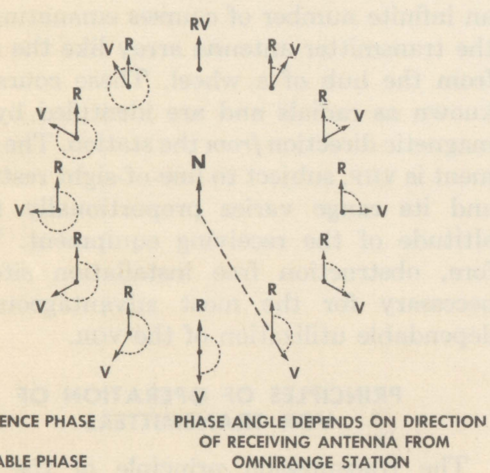


Figure 58—Phase angle relationships.

The two signals are initially aligned so that they are exactly in phase at magnetic north and in all other directions are out of phase. The ability to measure the difference in phasing between the REFERENCE AND VARIABLE phases, electronically, enables us to translate this measurement in terms of azimuth angle from magnetic north. (See Figure 58.)

PRINCIPLES OF RECEPTION

The airborne receiving equipment (AN/ARN-14) used to measure the phase difference is composed of three basic circuit groups: (a) frequency selector, (b) superheterodyne receiver, and (c) navigation circuits.

The frequency selector (see Figure 59) allows the pilot to tune the receiver to any one of 280 channels in the frequency range of 108 to 136 megacycles. This frequency range covers all the ILS, VAR, VOR and many VHF aeronautical communication Channels.

THE SUPERHETERODYNE RECEIVER—All radio waves which strike the aircraft's receiving antennae induce electrical impulses into the antenna. (See Figure 60.) It is the function of the receiver to select the impulses induced by the radio waves transmitted by the station

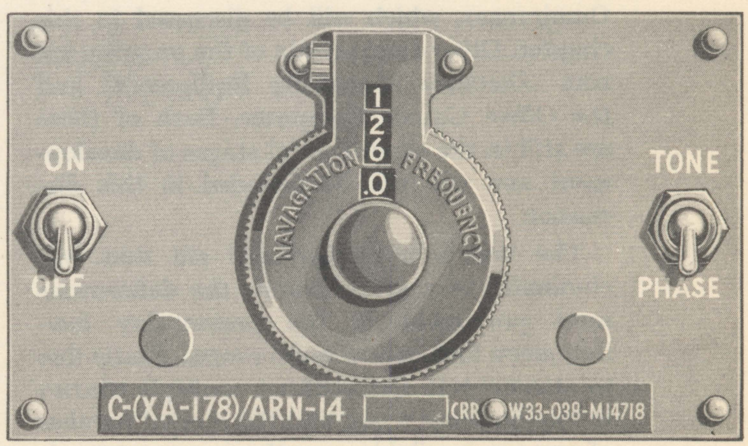


Figure 59—AN/ARN-14 Frequency Selector.

whose frequency has been tuned on the frequency selector, and to detect (convert) the modulations of these impulses into a usable form.

The navigation circuits are connected to two instruments, the Radio Magnetic Indicator and the Course Indicator (see Figures 61 and 62). The function of these instruments is to portray, visually on the instrument panel, the electrical information given them by the receiver in terms of position relative to the transmitting station.

The Radio Magnetic Indicator (Figure 61) combines the presentation of our present-day gyrosyn compass and radio compass. The circular compass card rotates as the aircraft turns, so that the heading of the aircraft will always be under the reference point at the top of the instrument. The double-barred needle always points toward the omni station to which the receiver is tuned. If the aircraft is headed directly toward the station the pointer of the double-barred needle and the magnetic heading of the aircraft will both be directly under the reference point at the top of the instrument. Should the aircraft be turned 90° to the right, the compass card will rotate 90° to the left. The double-barred needle will also rotate 90°, because it always points toward the station, but it rotates with the compass card and therefore its position relative to the compass card will not change except as the aircraft's position relative to the

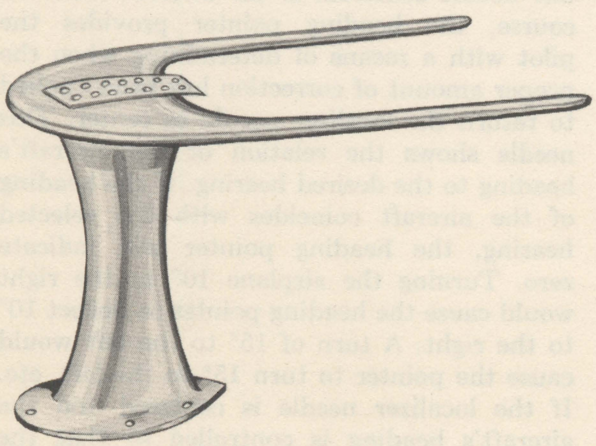


Figure 60—AN/ARN-14 Antenna.

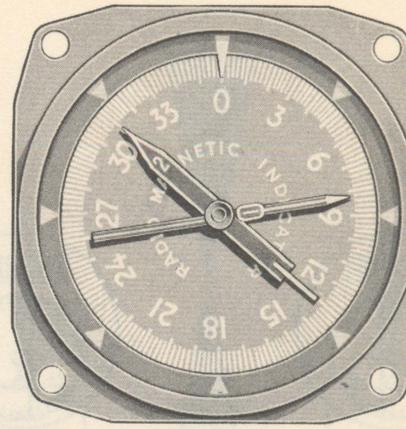


Figure 61—Radio Magnetic Indicator.

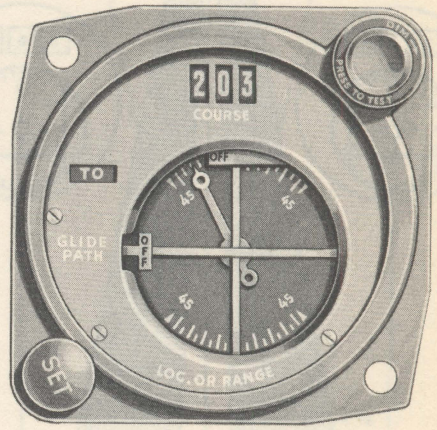


Figure 62—Course Indicator.

station changes. Thus, the indication of the double-barred needle will always be the *magnetic bearing* of the aircraft to the station. The single-barred needle is identical in operation. It is provided so that bearings on different stations may be taken simultaneously. This spare needle may be connected to a L/MF Radio Compass, or used in conjunction with a dual omni-receiver installation.

COURSE INDICATOR

The Course Indicator provides the pilot with a means of accurately flying TO or FROM the station on any desired bearing (see Figure 62. The bearing is selected in the bearing window by turning the knob provided for this purpose. The TO-FROM indicator will show whether the selected bearing is TO or FROM

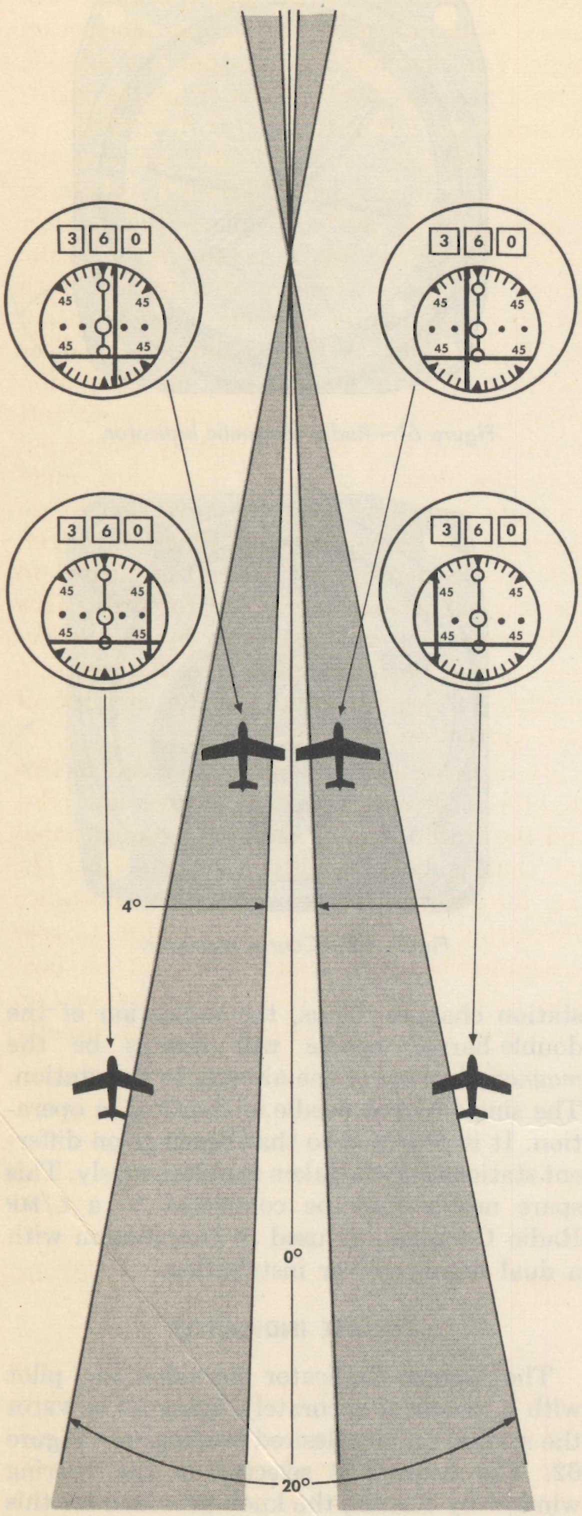


Figure 63—Relation of course width to pointer indications.

the station. Now assume that the RMI indicates that the magnetic bearing from the aircraft to the station is 360°. If 360° is selected on the bearing selector, the TO-FROM indicator will read TO. The localizer needle of the Course Indicator will be centered and will remain centered as long as the airplane remains on the 360° bearing. While flying north the pilot will be able to remain on course by turning toward the localizer needle whenever it moves off center, in the same manner as the ILAS is flown on the approach heading. When the station is passed the TO-FROM indicator will indicate FROM, but the 360° bearing can still be maintained from the station by correcting toward the localizer needle.

If the pilot executes a procedure turn without changing the bearing selector, the TO-FROM Indicator will still indicate FROM, but the airplane could be flown to the station on a 180° bearing by making corrections away from the localizer needle in the same manner as when flying the ILAS localizer on the reciprocal of the approach heading. However, the simplest method would be for the pilot to select the 180° bearing in the bearing window while he was performing the procedure turn. The TO-FROM Indicator would then indicate TO and the 180° bearing would be flown by making corrections toward the localizer needle.

The heading pointer has been provided to make it easier for the pilot to keep the localizer needle centered. If the aircraft drifts off course, the heading pointer provides the pilot with a means of determining when the proper amount of correction has been applied to return the localizer needle to center. This needle shows the relation of the aircraft's heading to the desired bearing. If the heading of the aircraft coincides with the selected bearing, the heading pointer will indicate zero. Turning the airplane 10° to the right would cause the heading pointer to deflect 10° to the right. A turn of 15° to the left would cause the pointer to turn 15° to the left, etc. If the localizer needle is centered and the aircraft's heading is controlled so that the bull's-eye of the heading pointer remains under

the localizer needle, the aircraft will remain on track under a no-wind condition. The magnetic heading would also coincide with the selected bearing.

Now assume that, under a no-wind condition, the localizer needle is indicating a full deflection to the right. This means that the airplane is on a bearing 10° or more to the left of the desired bearing. (The width of the Omnirange course is 20° from full deflection right to full deflection left of the localizer needle, 10° on either side of the center of the course.) (See Figure 63.) Although the airplane is to the left of the desired bearing, if the magnetic heading is the same as the selected bearing, the heading pointer will be on zero. To correct back to track, the aircraft is turned to the right until the bull's-eye of the heading pointer is under the localizer needle. (A correction of 45° is necessary to accomplish this when the localizer needle shows a full-scale deflection.) As the aircraft approaches the desired course the localizer needle will move to the left toward the center of the instrument. In order to keep the heading pointer under the localizer needle it will be necessary to turn the aircraft to the left. It can readily be seen that, as the aircraft approaches course, the interception angle will be gradually diminished and when the course has been reached the heading pointer and localizer needle will be centered and the magnetic heading will coincide with the selected bearing.

When a crosswind exists, the mechanical procedure of keeping the pointer under the needle will not give the proper correction angle. For example, assume that the aircraft is on track but the wind is from the right, causing 10° of left drift. If no drift correction is applied, the localizer needle will move to the right as the aircraft drifts to the left. Although a correction is made to place the pointer under the localizer needle as soon as the needle moves, the aircraft will continue to drift until the heading pointer deflects approximately 10° to the right. At this point the localizer needle will hold steady but no correction toward track is being made, and the aircraft is tracking in on a bearing slightly downwind from the desired bearing. The pilot must compute and make a larger correction to reintercept the desired bearing. When the deviation needle centers, the aircraft is turned to the original heading corrected for drift. This drift correction will be shown by the deflection of the heading pointer to the right, a number of degrees equal to the amount of drift correction applied.

By utilizing the principles discussed in this chapter it is now possible to give the pilot and the traffic control agencies a navigational aid that is both versatile and practical. In the foreseeable future, when the Distance Measuring Equipment, and the Offset Course Computer become standard, it will be possible to fly a straight line course between two terminals, neither of which is served directly by an omnirange.

A GLOSSARY TO PART TWO

Absolute Altitude—Actual height (of an aircraft) above the earth.

AC—Abbreviation for alternating current.

ADF—Abbreviation for automatic direction finder or automatic direction finding.

Aerodynamic Drag—The resistance, caused by air, to any object moving through the air.

Air Speed—The speed at which an aircraft travels through the air, in contradistinction to its speed over the ground.

AM—Abbreviation for amplitude modula-

tion. (Refer to *amplitude modulation.*)

Amplitude Modulation—A method of modulating a carrier-frequency current by causing its amplitude to vary above and below its normal value in accordance with an audio or other signal.

A-N Signals—Radio range quadrant designation signals, which indicate to the pilot whether he is on course, or to the right or left of course.

Aneroid Barometer—A barometer which depends upon the deflections of a pressure-sensitive element, the aneroid, for its indications. The aneroid of the cell actuates a needle which indicates the pressure changes on a calibrated scale.

Arbitrary Course—A course chosen at one's discretion.

Automatic Pilot—A control mechanism which initiates corrections in control surfaces to maintain a steady and present course without assistance from the human pilot. Also called gyropilot, robot pilot, and mechanical pilot.

AVC—Abbreviation for automatic volume control.

Azimuth Angle—The angular measurement in a horizontal plane and in a clockwise direction, beginning at a point oriented to north.

Azimuth Stabilization—The presentation of indications on a scope so that north is always at the top of the scope.

Barometric Altimeter—An altimeter, the indications of which depend upon the deflection of a pressure-sensitive element. (Refer to *aneroid barometer.*) The graduations of the dial corresponds to an empirical or arbitrary pressure-temperature-altitude formula.

Bearing—Measure of a direction in azimuth with respect to true north, magnetic north, or any other bearing.

Blind Landing—Landing with no external visibility. All flight, approach, and landing information used by the pilot are obtained from instruments in the aircraft and from ground radio direction devices.

Climatological Path—An optimum flight path, atmospheric conditions taken into account.

Clutter—Radar signals from ground, sea, or other reflectors, appearing on an oscilloscope and interfering with observation of the desired target signals.

CPS—Abbreviation for cycles per second.

CRT—Abbreviation for cathode-ray tube, a device which transforms an electrical impulse into an optical image.

CW—Abbreviation for continuous wave.

DC—Abbreviation for direct current.

DF—Abbreviation for direction finding or direction finder.

Drift Angle—The angle between the heading of an aircraft and its track or flight path over the ground.

Equisignal (sector)—The on-course region in which the two different signals from an equisignal radio range beacon are received in an aircraft with equal intensity.

FIDO—Abbreviation for fog, intense, dispersal of.

Fix—A definite position of an aircraft determined by radio, celestial, or other means.

Flux-Gate Compass—A trade name used by Eclipse Pioneer Division of the Bendex Aviation Corporation for a gyrostabilizer, earth inductor, remote indicating compass which is used as a compass and azimuth control system in conjunction with automatic pilots.

FM—Abbreviation for frequency modulation. (Refer to *frequency modulation.*)

Fog Dispersion—Any technique for dissipating fog by artificial means. For example, FIDO.

Frequency Modulation—A method for modulating a radio-frequency current by causing the frequency of the current to vary above and below the normal resting frequency in accordance with an audio or other signal, the amplitude of the carrier remaining constant at all times.

GCA—Abbreviation for ground controlled approach; a mobile radar unit used to track friendly aircraft and direct them by radio into a safe landing during conditions of very low visibility.

GCI Abbreviation for ground controlled interception; a radar system employing a controller who directs fighter planes to an interception point.

Gibson Girl—A portable, hand-operated transmitter for use by pilots forced down at sea to send out information as to location.

Glide Path—The part of an instrument landing system which produces a radiation pattern that creates in space a recognizable electronic glide path for blind landing. Establishes the vertical position of the aircraft. Used in conjunction with the localizer, which establishes the lateral position.

Goniometer—As applied to a radio range system, a device for shifting the directional characteristics of an antenna without moving the antenna.

GPI—Abbreviation for ground position indicator. An extension of the air position indicator in which ground position is determined by adding ground speed and drift readings to the air position data.

Grass—Cathode-ray tube clutter due to noise. (Refer also to *clutter.*)

Ground Speed—The speed at which an aircraft travels over the surface of the earth, in contradistinction to its speed through the air.

Ground Waves—One of two general types of radio waves. Ground waves follow the surface of the earth and are commonly used for radio communication on long wave lengths. (Refer also to *sky waves.*)

Heading—The direction in which the aircraft is pointed in contradistinction to its path over the ground.

HF—Abbreviation for high frequency; a Federal Communications Commission designation for the band from 3 to 30 megacycles in the radio spectrum.

Homing—The procedure of flying an aircraft toward a transmitting station by means of a radio direction finder or radar without regard to position fixes. Also homing on a target in a radar equipped aircraft.

ICAO—Abbreviation for International Civil Aviation Organization.

IFF—Abbreviation for identification, friend, or foe; a system of pulse-type radio interrogation and reply, generally used in connection with radar for aircraft and ship identification.

Impedance—The apparent resistance in a circuit to the flow of an alternating current, analogous to the actual resistance to a direct current. Also, the ratio of pressure to volume displacement at a given surface in a sound transmitting medium.

Indicator (radar)—A cathode-ray tube used to transform an electrical impulse into an optical image.

In Phase—The condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same time.

KC—Abbreviation for kilocycle (s).

KVA—Abbreviation for kilovolt ampere (s).

KW—Abbreviation for kilowatt (s).

LF—Abbreviation for low frequency; a Federal Communications Commission designation for the band from 30 to 300 kilocycles in the radio spectrum.

Line-Of-Position—A short section of a circle of position, in reality, a tangent to a circle of position.

Line-Of-Sight—Ranges to which radar and radio equipment operating at very-high and higher frequencies are limited because of the curvature of the earth.

Lobe-Switching—Directing a radio frequency beam rapidly back and forth between two positions. Used for accurate direction finding.

Localizer (runway)—A small radio range beacon used to provide accurate directional guidance along the runway and for some distance beyond.

Loran—Abbreviation for *long range navigation.*

Master Station—The station of the LORAN pair whose timing crystal, running free, sets the pulse rate for the pair. Usually, the A-type station operates as the master.

MC—Abbreviation for megacycles (s).

MCW—Abbreviation for modulated carrier wave (s).

MF—Abbreviation for medium frequency; a Federal Communications Commission designation for the band from 300 to 3,000 kilocycles in the radio spectrum.

Millibar—A unit of pressure, used in measuring atmospheric pressure, which is nearly the pressure of .0295 inches of mercury at 32° F. and under standard conditions of gravity.

Modulation—The process of varying the amplitude or the frequency of a carrier wave in accordance with signals in order to convey intelligence. The modulating signal may be an audio-frequency signal, video signal (as in television), or even electrical pulses or tones to operate relays, etc.

MRL—Medium-powered Range Adcock antenna.

Omnidirectional—Directionally universal, with regard to the points of the compass.

On-Course Signal—A steady monotone radio signal which indicates to the pilot that he is neither too much to the right nor to the left of the radio beam followed.

Optimum Flight Path—The most desirable route to follow, all flight conditions considered.

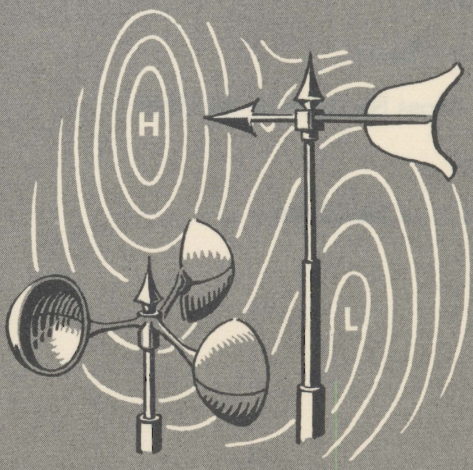
Oscilloscope—An instrument which makes possible the visual inspection of audio or radio frequency signals. It consists usually of three major parts: an amplifier, time base generating circuits, and cathode-ray tube for translation of electrical energy into light energy.

Out-Of-Phase—Having wave forms that are of the same shape, but which do not pass through corresponding values at the same instants.

PPI—Abbreviation for *plan position indicator*.

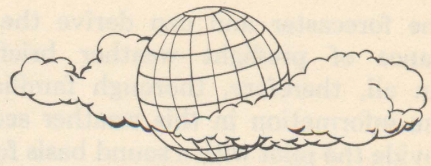
Part 3

Weather Principles and Practices



Outline to Part 3

CHAPTER TWENTY-EIGHT



Circulation

GENERAL

An all-weather Air Force means "flight anywhere at any time." Naturally, putting this slogan into effect frequently exposes the pilot to many problems. The pilot who is aware of these problems, understands them, and prepares himself to cope with them, obviously is far less likely to get into trouble than the pilot who is ignorant of the fact that the problems exist or who does not understand the nature of the problems and how to cope with them.

Basically, understanding the problems of all-weather flight means understanding the weather. This is not to say that the pilot has to be a weather forecaster and be thoroughly familiar with all the techniques and procedures the forecaster has to know. It does mean, however, that the pilot has to understand the weather forecaster's language and the general principles by which the forecaster is guided. With such knowledge, the pilot can make the best use of the information the forecaster gives him, can logically plan out an instrument flight, and can intelligently deal with all weather situations, both predicted and unpredicted.

The aim of the weather section in this manual, therefore, is to present the basic principles of modern meteorology in terms applicable to the Air Force pilot. For that reason, mathematical theorems and formulas have been omitted from the text and the material has been made as practical as possible. Of course, a considerable amount of material in this chapter and the chapters up to 36 deal with the fundamental concepts of weather theory. But this, too, has been limited to that which a pilot needs in order to understand the practical weather phenomena with which he will have to cope. Thus, the material on circulation is placed in this first chapter in the weather section because it is the stepping stone to an understanding of all the other weather phenomena. Without a thorough understanding of this fundamental process, one cannot hope to understand such things as air masses, fronts, and thunderstorms.

On the practical side, chapters 36 through 43 deal with the forecaster's methods of observing, analyzing, and reporting the weather situation. At first glance, some of this material and terminology may seem to be beyond the scope of the pilot's requirements. Closer examination, though, will show that knowledge of this material is essential to the pilot so that he can have a common meeting ground

with the forecaster and can derive the full significance of preflight weather briefings.

All in all, therefore, thorough familiarity with the information in this weather section will provide the pilot with a sound basis for interpreting and evaluating the various factors in the weather situation as they apply to him.

CIRCULATION

On any flight, regardless of its extent, whether it covers eight thousand miles or just a few miles on a local transition hop, the pilot is concerned with the wind. Winds are the tangible result of the circulation of the earth's atmosphere and therefore are discussed in terms of circulation. The basic definition of circulation is: to move from a point by a circuitous course back to the starting point.

Circulation in terms of meteorology is the movement of air over the surface of the earth. This movement is continuous throughout the entire atmosphere, but we are mostly concerned, in this discussion, with the movement of air in the troposphere. The troposphere can be compared to the cover on a baseball except that at the equator it is thicker than it is at the poles. The air within the troposphere is subject to changes in density and temperature the same as water or any other fluid, and since air is a fluid, it reacts in much the same manner as confined liquids. Before any movement can begin within a confined liquid, however, there must be a differential in densities between two or more portions of the fluid. In the atmosphere, in most cases, this difference in density is a result of a difference in temperature as gasses such as air vary in density with temperature changes.

The temperature differential in the atmosphere which causes atmospheric circulation

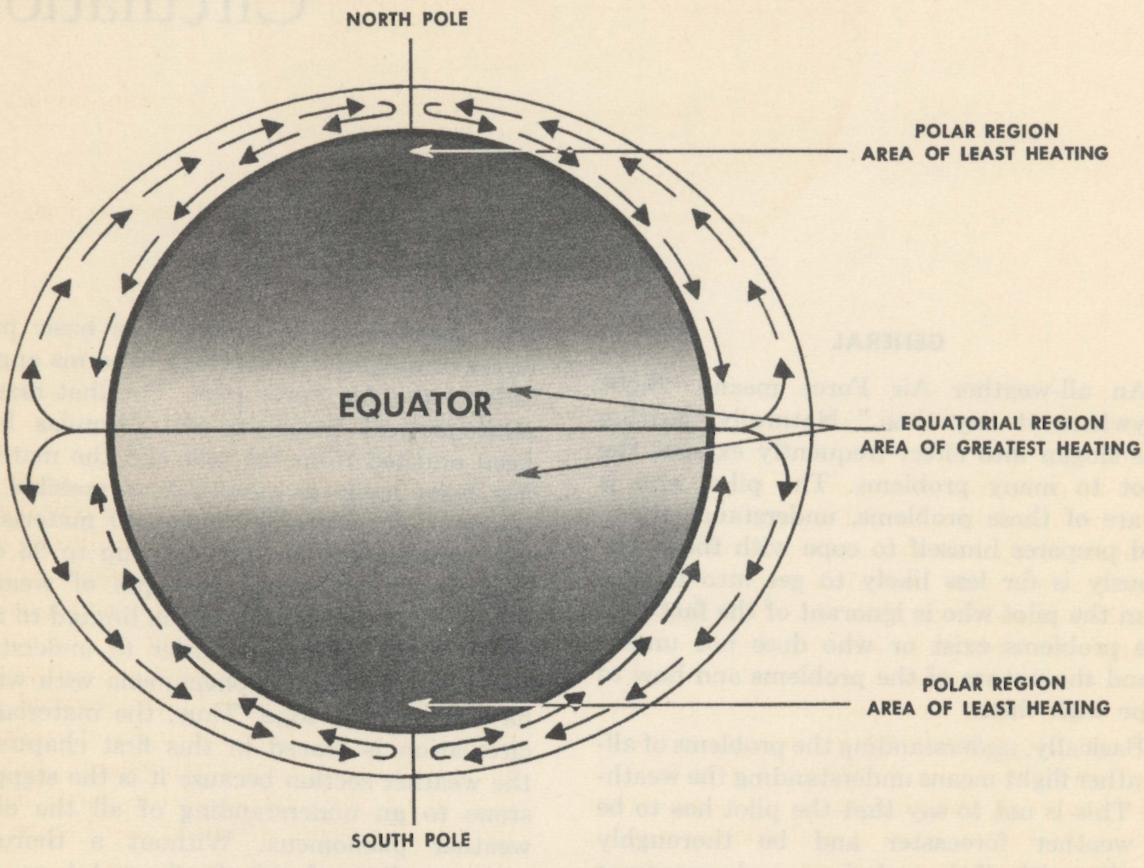


Figure 1—Simple circulation.

Figure 2—Three cell theory zones.

can be compared to the temperature differential produced in a pan of water placed over a Bunsen burner or some other heating device. As the water is heated it expands and its density is reduced. This reduction in density causes the water to rise to the top of the pan, and as it rises it cools and proceeds to the edges of the pan. Upon reaching the edges of the pan it cools further and sinks to the bottom, eventually working its way back to the center of the pan where it started from. This process of heating and cooling sets up a simple circulation pattern.

Simple circulation in the atmosphere would occur in much the same manner if it were not for the following facts: (1) the earth is covered with an irregular surface, (2) the earth rotates, so that the area being heated changes constantly, and (3) the annual changes in the plane of rotation causes changes in the amount of heat being received by any specific area of the earth's surface.

The air within the confines of the troposphere may be compared to the water contained in the pan, and the sun which heats the air can be compared with the Bunsen burner. The most direct rays of the sun hit the earth in the vicinity of the equator which causes a net gain of heat at the equator and a net loss of heat at the poles. The air at the equator is heated and rises and flows along the upper extremities of the atmosphere toward both poles. Upon reaching the poles it cools and sinks back toward the earth where it tends to flow along the surface of the earth back to the equator where it started (see Figure 1).

There is a theory regarding the circulation pattern of the earth's atmosphere known as the three-cell theory. In this theory the earth is divided into six latitude belts, three in the northern hemisphere and three in the southern hemisphere. The dividing lines between these three belts in each hemisphere are: (1) the equator, (2) 30° N. and S., and (3) 60° N. and S. This results in three belts of latitude in each hemisphere, one between the equator and 30°, one between 30° and 60°, and one between 60° and the pole (see Figure 2).

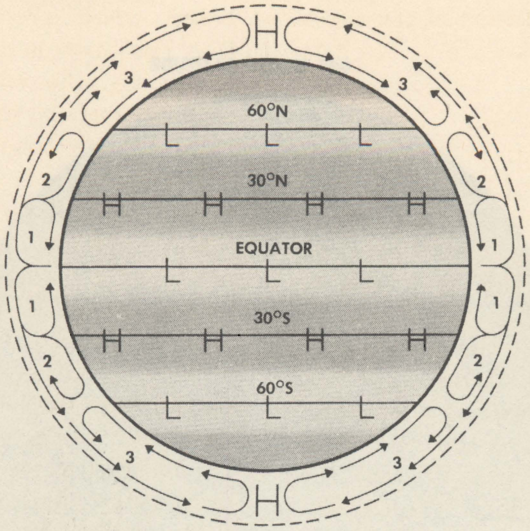


Figure 3—World circulation pattern.

The air at the equator is heated and rises, thus creating a low-pressure area at the surface. When this warm air reaches the extremity of the atmosphere, it tends to flow toward the poles. The air necessary to replace the warm air that has ascended is obtained theoretically from the same air that has gone aloft, because in the vicinity of 30° latitude, air is constantly descending toward the surface from altitudes within the atmosphere. When this descending air reaches the surface, part of it flows toward the equator to replace that which has gone aloft and part of it flows northward toward the pole in the northern hemisphere. The converse is true in the southern hemisphere. As a result of this piling up of air in the area of 30°, there is formed a belt of high pressure in this area which is one of the three cells of circulation.

The second cell of circulation is located between 30° and 60°. In this cell the circulation pattern is much more involved than the pattern in the first cell, since the flow of air is complicated by traveling cyclones and anticyclones. Although the general flow of air in the second cell is toward the poles, it is de-

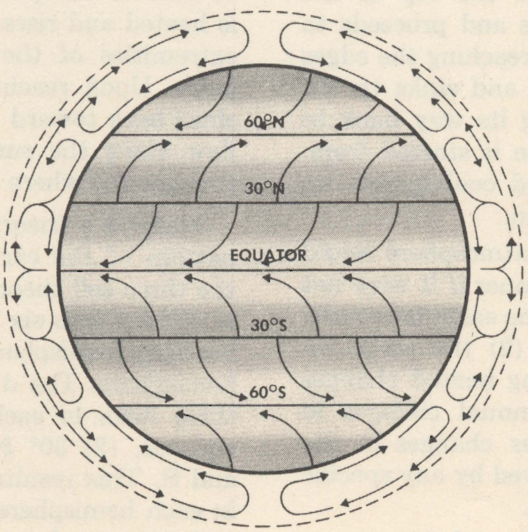


Figure 4—Direction of prevailing winds on the earth's surface.

flected to the east by the rotation of the earth (coriolis force). This cell is known as the belt of prevailing westerlies.

The third cell of circulation (Figure 3) lies between 60° and 90° latitude. The circulation of this cell begins with a flow of air at a high altitude toward the poles. Air which is forced to rise by the circulation in the second cell and by the heating in this area adds to the primary flow of air from the first cell. This flow of air continues to the poles where it is cooled and descends, forming a more or less static high pressure area in the polar regions. When the air reaches the surface of the earth, it tends to flow back toward the equator near the earth's surface. The circulation in this cell is completed by the southerly flow of air toward the equator. This air converges with the poleward flow from the second cell and is deflected upward. This conversion causes a semi-permanent low pressure area at this latitude and the discontinuity in temperature and density of the two bodies of air causes a front (called the polar front) to form in this area.

In Figure 3, the circulation pattern is shown according to the three-cell theory but the rotation of the earth on its axis is not considered. As the earth rotates, circulation is affected by friction and coriolis force. The result is that the winds are deflected to the right of the original direction of movement in the northern hemisphere and to the left of the original direction of movement in the southern hemisphere (see Figure 4).

All of the earth's atmospheric circulation is based on a differential in heating. The source of this heating is the sun, and as a result of the variation in the intensity of the sun's rays on the surface of the earth with a change in season, these areas of differential heating do not always remain in the same geographical location but fluctuate with a change in season. All diagrams of the ideal circulation pattern on the earth are based on the average position of these areas of differential in heating, and they assume that the earth has a uniform surface with respect to color, shape, and texture.

All of the preceding discussion has been based upon the hypothetical assumption that the earth is of uniform surface. Now let us discuss the effect of the existent, non-uniform surface, upon the circulation pattern in the lower levels of the atmosphere. The vast difference in adjacent terrain types causes many local deviations from the classified primary circulation theory. Friction with the surface of the earth and the barrier presented by great mountain ranges towering 3 to 5 miles into the atmosphere produce definite changes in the flow. Differential in heat absorption potential (specific heat) between adjacent land and water surfaces is a very important factor in accounting for local variations from the primary circulation pattern. In effect, any of these variations from the basic meridional circulation pattern discussed under the heading of Primary Circulation must be taken into consideration in studying the over-all picture of atmospheric motion and may be classed as Secondary Circulation.

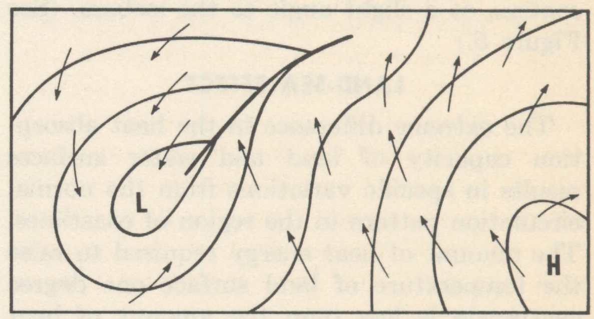
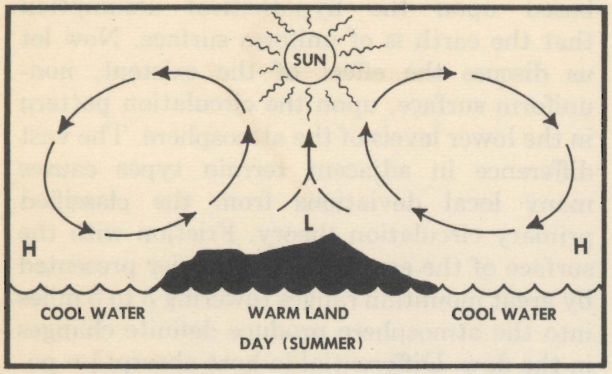


Figure 5—Surface wind flow as result of friction.

The effect of mountains upon the air flow in the levels penetrated by this terrain feature is obvious. Flow which has been perpendicular to a mountain range or peak will be caused to deviate from normal and in many cases will be caused to parallel the range.

Between the earth's surface and about 2000 feet, airflow is affected considerably by friction. Above this level the effect of friction decreases rapidly and may be considered negligible for purposes of practical analysis. Outside of the effect of friction air flow is parallel to lines of equal pressure (isobars). This is true because there is a balance between the pressure gradient force, away from the



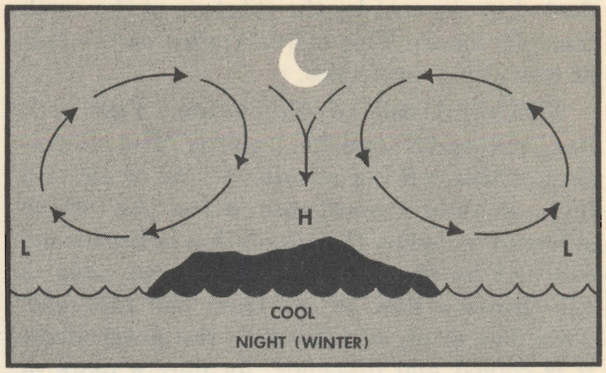


Figure 6—Land-sea effect.

high pressure center, and coriolis force which is always to the right in the northern hemisphere. However, coriolis force is dependent upon the velocity of the air flow. Since friction decreases this velocity, the balance of forces is disrupted, making the air near the surface (up to 2000 feet) flow out from the high pressure center and in toward the low centers, at a slight angle to the isobars. (See Figure 5.)

LAND-SEA EFFECT

The extreme difference in the heat absorption capacity of land and water surfaces results in specific variations from the normal circulation pattern in the region of coastlines. The amount of heat energy required to raise the temperature of land surface one degree centigrade is less than the amount of heat required to raise the temperature of the same area of water one degree centigrade. On the other hand, when the heat source is removed (sunset or wintertime) land will cool much more quickly than water. This effect, in general, causes a land surface to be warmer than an adjacent water surface in the daytime and a water surface to be warmer than an adjacent land surface at night. (This same effect takes place from season to season on a larger, less apparent scale.) The relatively warmer land surface causes convective heating of air in the lower levels over land by day. In these lower levels air will then begin to flow from the water to the land (sea breeze). This general effect also occurs all through the summer season. The exact reverse occurs at night and in the winter. (See Figure 6.)

The sum total of this land-sea effect is a change in circulation along coastlines from day to night and from season to season. Moreover, a general area of convergence is effected just inland part of the time and just off-shore the remainder of the time.

CHAPTER TWENTY-NINE

29

Adiabatic Processes and Stability

GENERAL

The processes that determine the weather are dependent partly upon the transfer of heat and moisture and partly on the forces that create and maintain the motion in the atmosphere. This discussion is related to temperature changes caused by expansion and contraction of air as it moves upward or downward. Air that moves upward comes under lower pressures and expands, while air that moves downward comes under higher pressures and contracts. When air expands it cools, and when it contracts it warms, even though outside heat is neither supplied nor withdrawn during the expansion or contraction process. These resultant changes in temperature are said to be adiabatic changes in temperature. A process is said to be adiabatic when no heat is added to nor withdrawn from the air that partakes in the process.

To explain the changes in temperature in the atmosphere further, it is necessary to go into some detail on the physical makeup of the atmosphere, or, as we more commonly think of it, air. Air, or a mixture of gases such as air, is made up of a large number of molecules in a state of incessant and irregular motion which leads to frequent collisions between the molecules. The pressure of the gas depends upon the number and mass of the molecules in the mixture and the speed with which they are moving. The number and mass of the molecules per unit area is the density of the gas. The pressure is proportional to the density. The speed at which the molecules move depends upon the temperature of the mass; therefore, the pressure must be proportional to the temperature of the gas.

To explain the preceding paragraph simply, apply the stated physical changes to the atmosphere. If a parcel of air is lifted, it will come under a lower pressure; if the pressure is lowered, the temperature is also decreased. It follows then, that if a parcel of air is made to descend, it will come under a higher pressure; if this pressure is higher the density becomes greater, and if the density is greater, the temperature must necessarily become greater. It should prove very helpful to keep these thoughts in mind during the discussion on adiabatic processes in the atmosphere.

DRY ADIABATIC PROCESS

The first process to be discussed is the only true adiabatic process to be found in the free

air or atmosphere. This process occurs with the ascent and descent of dry or nonsaturated air. Air is considered to be dry or nonsaturated if the relative humidity is less than 100 per cent. Free air is the air that is found above the level that is in close proximity to the surface of the earth. This is necessary because of the great heating and cooling effect that the earth has on the layer of atmosphere that is in contact with it. For example, it can be proved that the temperature decreases at a uniform rate as altitude is gained by noting temperature changes as an ascension is made in a vertical column of nonsaturated air which is not modified in any manner by an outside source. This uniform rate of temperature decrease, which is called the "dry lapse rate," is expressed in degrees centigrade and feet and in this case the change would be 3° C. for every thousand feet change in altitude. It seems reasonable also that if any parcel of air within this column were displaced vertically, its temperature would change according to the dry lapse rate. This uniform change in temperature occurs whether the parcel is descending or ascending; while ascending the parcel cools at 3° per 1,000 feet and while descending it warms at 3° C. per 1,000 feet.

A column of nonsaturated air that has been modified by some outside source may have a lapse rate that is less than the standard dry lapse rate. Even though this column has a lesser lapse rate than the dry lapse rate, any particle or parcel of air that is displaced vertically cools or warms according to the dry lapse rate.

MOIST ADIABATIC PROCESS

Saturated air containing visible water vapor has a modifying effect upon the temperature of that air. This is due to the latent heat of evaporation. When water is brought to the boiling point (at sea level), the temperature of the water remains at 100° C. until all of the water has been evaporated. The heat that is applied does not raise the temperature of the water above 100° C., but the vapor that is escaping into the atmosphere is carrying with it the excess heat. This is necessary in order to keep the water in the vapor state. It follows then that water vapor contains a certain amount of heat. It is also logical to assume that if this water vapor is condensed, it must give off the heat that was keeping it in the vapor state. Knowing this helps to understand the modifying effect that visible moisture has upon the temperature of the air.

To understand the lapse rate of moist or saturated air, consider what happens when a column of air has moisture dispersed throughout its vertical extent. The primary factor in determining the lapse rate of any column of air is the changes in pressure with changes in altitude. When speaking of moist air, however, the liberated latent heat of condensation must be considered when evaporation occurs. Air cools as altitude is gained, but because of the latent heat of evaporation, it will not cool as rapidly as the dry air. Another factor that must be considered when speaking of moist air lapse rate is the original temperature of the air column, because it is known that relatively warm air can hold much more moisture per unit volume than can relatively cold air. Thus, the amount of water vapor available to liberate heat is dependent upon the temperature of the air. The modifying effect of moisture on warm, moist air reduces the lapse rate much more than that of cold, moist air.

The actual lapse rate of relatively warm, moist air is about one-half that of the dry lapse rate of 1.5° C. per 1,000 feet, while the lapse rate of cold, moist air is nearly the same as that of dry air, or about 3° C. per 1,000 feet. If there were two saturated air masses, one with a temperature of 20° C. and one with a temperature of −20° C., the air mass with a temperature of 20° C. at the saturation point could hold approximately 14 grams of water vapor per Kg. of air; while the air mass with a temperature of −20° could hold only .75 grams of water vapor per Kg. of air. This relationship of the number of grams of water vapor per kilogram of air is referred to as specific humidity or mixing ratio. An analysis of this comparison reveals that the warmer of the two air masses has a larger modifying potential in the form of latent heat

analysis is the wet reference line. This line depicts the lapse rate of moist or wet air and slopes much in the same manner as that of the dry line except that its angle is steeper near the surface, and it curves sufficiently as it nears the top of the diagram so that it is nearly parallel to the dry reference lines. (See Reference KL, Figure 7.)

Mixing Ratio Line

The third reference line that aids analysis is the mixing ratio line which, with the numerical data accompanying the line, gives information on the amount of water vapor the air could possibly hold at a given pressure and temperature. This information is expressed in grams of water vapor per kilogram of air. (See Reference MN, Figure 7.)

Standard Lapse Rate Line

The fourth reference line which aids analysis is the standard lapse rate line. This line indicates the lapse rate of the standard atmosphere, and is used only for comparison of the free-air curve to the standard atmosphere. This line slopes from upper left to lower right on the diagram. Its temperature is plus 15° C. at 1013.2 millibars (sea level), decreasing to minus 32° C. at 400 millibars. (See Reference OP, Figure 7.)

USE OF THE ADIABATIC CHART

By using the background information presented in the first portion of this discussion and the information concerning the reference lines of the diagram, we are now able to utilize the entire diagram in analyzing the atmosphere depicted by the free-air curve. (See Reference QR, Figure 7.)

Simple atmospheric analysis can be divided into analysis concerning temperature and analysis concerning moisture content; and these two steps, in turn, can be subdivided as follows:

Temperatures at Flight Altitude

To determine the temperature at any altitude of flight and from the adiabatic diagram, first choose the altitude. Locate this altitude

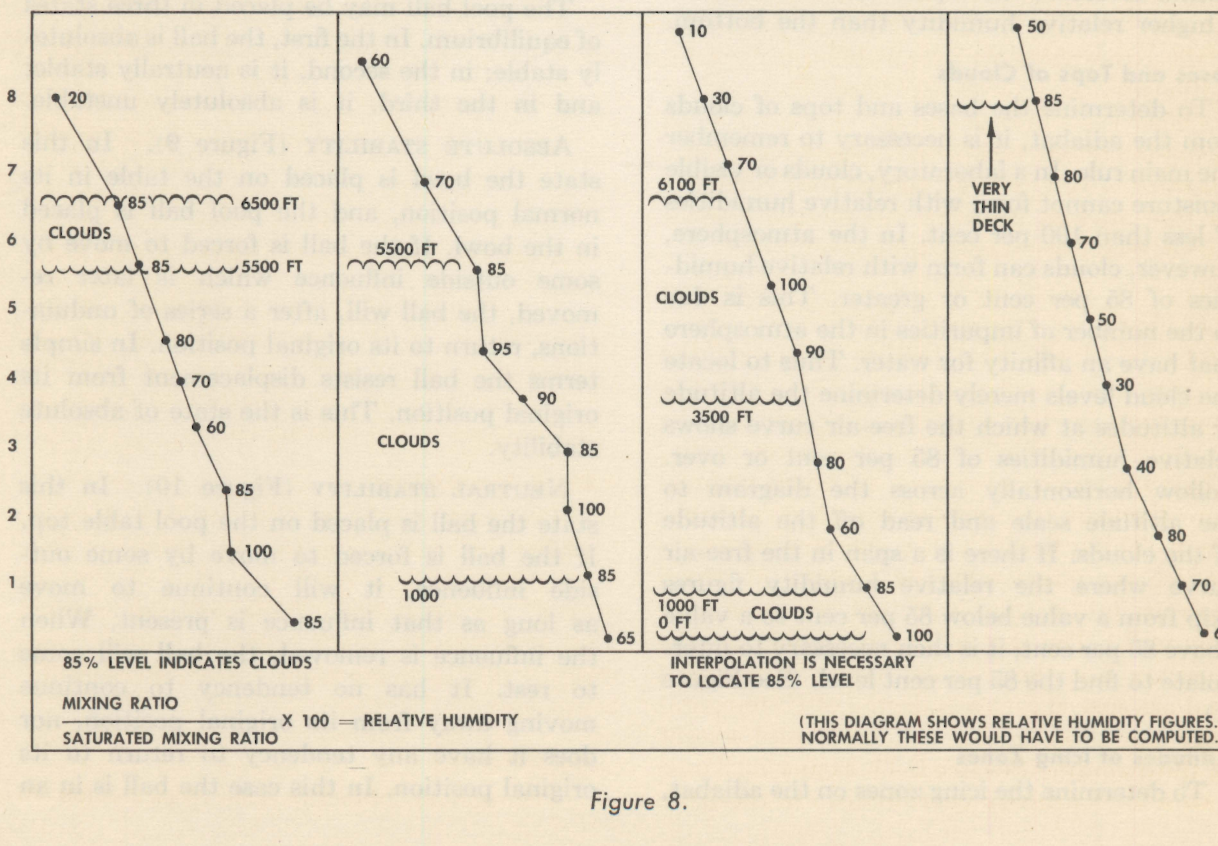


Figure 8.

on the marginal altitude scale of the diagram. Follow from this point horizontally across the diagram until you intersect the free-air curve. Now move straight down from this point to the temperature scale at the bottom of the diagram and read off the temperature.

Altitude of Freezing Level

To determine the altitude of the freezing level, follow up the 0° isotherm until it intersects the free-air curve. Move from this point horizontally across to the altitude scale and read off the altitude.

Inversions. (Surface, Subsidence, and Frontal)

To locate an inversion on the adiabatic diagram, find a portion of the free-air curve that indicates an increase in temperature with altitude. A surface inversion will be at or near the surface. A subsidence inversion can be identified by the moisture distribution. In a subsidence inversion the top of the inversion has a lower relative humidity than the bottom. A frontal inversion can be identified also by its moisture distribution. In a frontal inversion the top of the inversion has a higher relative humidity than the bottom.

Bases and Tops of Clouds

To determine the bases and tops of clouds from the adiabat, it is necessary to remember one main rule. In a laboratory, clouds or visible moisture cannot form with relative humidities of less than 100 per cent. In the atmosphere, however, clouds can form with relative humidities of 85 per cent or greater. This is due to the number of impurities in the atmosphere that have an affinity for water. Thus to locate the cloud levels merely determine the altitude or altitudes at which the free-air curve shows relative humidities of 85 per cent or over. Follow horizontally across the diagram to the altitude scale and read off the altitude of the clouds. If there is a span in the free-air curve where the relative humidity figures skip from a value below 85 per cent to a value above 85 per cent, it is then necessary to interpolate to find the 85 per cent level. (See Figure 8.)

Altitudes of Icing Zones

To determine the icing zones on the adiabat, it is necessary first to locate that portion of the free-air curve that lies in the temperature zone below 0° C. and then determine whether there are clouds present. If there are no clouds present, then there is no ice. To find the altitude of the icing zone, considering the fact that there are temperatures below freezing and relative humidities above 85 per cent, follow horizontally from these points to the altitude scale and read off the altitudes.

DEFINITION OF STABILITY

In order to analyze the atmosphere further as depicted by the free-air curve, it is necessary to know the stability of the atmosphere. Stability of the atmosphere may be compared with the stability which is necessary for an individual to maintain his balance while standing or walking. In the following, an illustration about a pool ball, a round bottom bowl, and a pool table is used to explain simple stability and instability.

States of Equilibrium

The pool ball may be placed in three states of equilibrium. In the first, the ball is absolutely stable; in the second, it is neutrally stable; and in the third, it is absolutely unstable.

Absolute stability (Figure 9). In this state the bowl is placed on the table in its normal position, and the pool ball is placed in the bowl. If the ball is forced to move by some outside influence which is later removed, the ball will, after a series of undulations, return to its original position. In simple terms the ball resists displacement from its original position. This is the state of absolute stability.

Neutral stability (Figure 10). In this state the ball is placed on the pool table top. If the ball is forced to move by some outside influence, it will continue to move as long as that influence is present. When the influence is removed, the ball will come to rest. It has no tendency to continue moving away from its original position, nor does it have any tendency to return to its original position. In this case the ball is in an

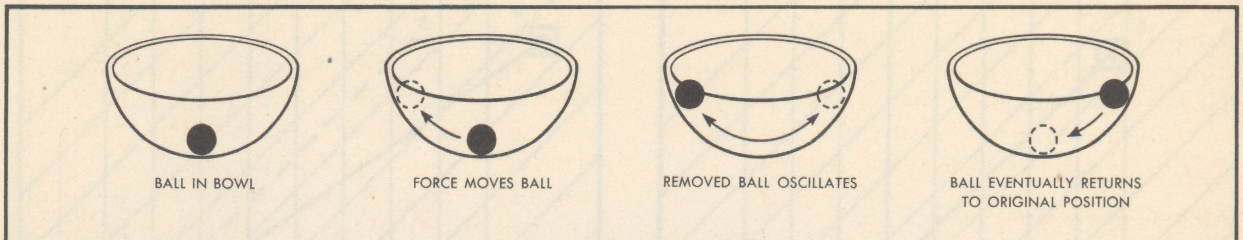


Figure 9 — Absolute stability.

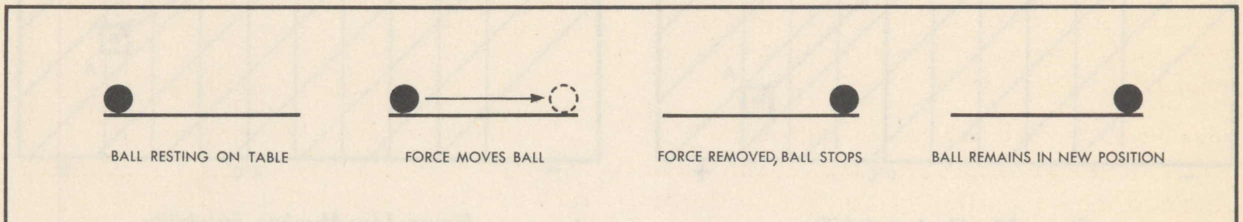


Figure 10 — Neutral stability.

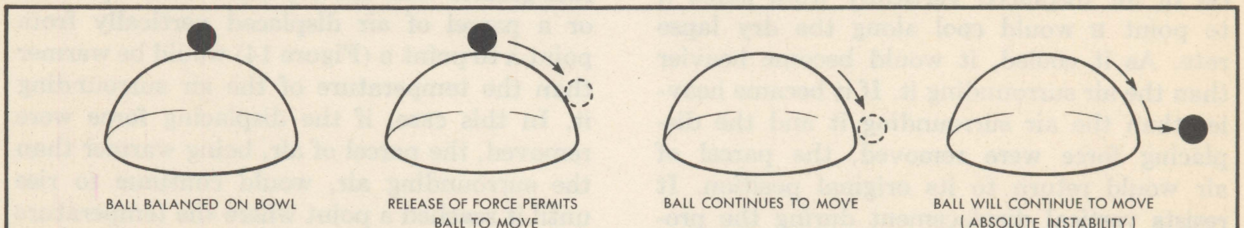


Figure 11 — Absolute instability.

indifferent state of stability which is termed neutral stability.

ABSOLUTE INSTABILITY (Figure 11). In this state the bowl is inverted on the table top and the ball is balanced on the bottom of the inverted bowl. If the ball is released when it is in this precarious position, it immediately begins moving away from the original position and makes no attempt to return to its original position. This is a state of absolute instability.

ATMOSPHERIC STABILITY

The atmosphere reacts in much the same manner as does the pool ball. The difference is that the atmospheric stability is dependent upon vertical temperature lapse rates. It is impossible for air that is cold and heavy to remain on top of warmer and lighter air.

Absolute Stability

In the case of absolute stability, a portion of the free-air curve showing dry air can be compared to the dry lapse rate lines to determine its stability (see Figure 12).

With the free-air curve showing a lapse rate less than the dry lapse, a particle or par-

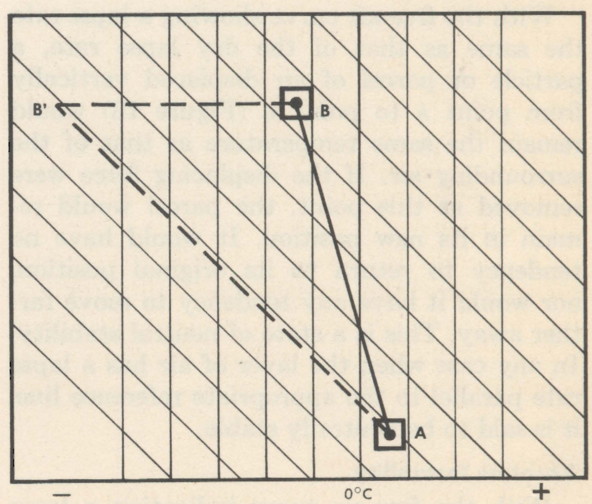


Figure 12—Absolute stability.

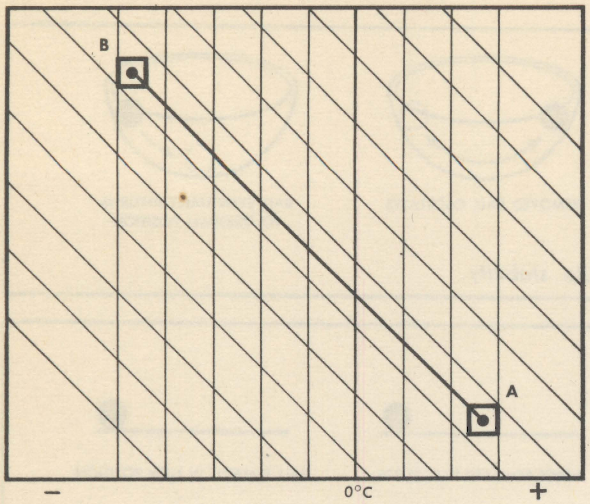


Figure 13—Neutral stability.

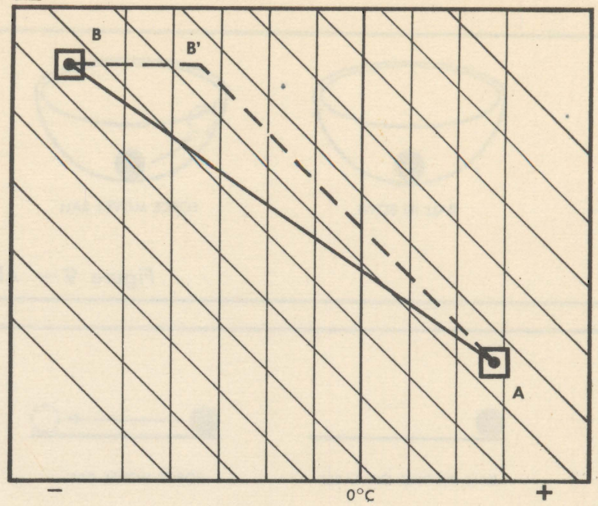


Figure 14—Absolute instability.

cel of air displaced vertically from point A to point B would cool along the dry lapse rate. As it cooled, it would become heavier than the air surrounding it. If it became heavier than the air surrounding it and the displacing force were removed, the parcel of air would return to its original position. It resists vertical displacement during the process; therefore, it is in a state of absolute stability. If this layer of air indicated on the free-air curve were moist, then the process would be compared to the wet lapse rate line. In any case when the free-air curve slopes to the right of the appropriate lapse rate line, the layer of air is stable.

Neutral Stability

With the free-air curve showing a lapse rate the same as that of the dry lapse rate, a particle or parcel of air displaced vertically from point A to point B (Figure 13) would remain the same temperature as that of the surrounding air. If the displacing force were removed at this point, the parcel would remain in its new position. It would have no tendency to return to its original position, nor would it have any tendency to move farther away. This is a state of neutral stability. In any case when the layer of air has a lapse rate parallel to the appropriate reference line, it is said to be neutrally stable.

Absolute Instability

With the free-air curve indicating a lapse rate greater than the dry lapse rate, a particle or a parcel of air displaced vertically from point A to point B (Figure 14) would be warmer than the temperature of the air surrounding it. In this case, if the displacing force were removed, the parcel of air, being warmer than the surrounding air, would continue to rise until it reached a point where the temperature of the surrounding air is the same as its own. This is a state of absolute instability. In any case when the free-air curve shows a lapse rate greater than the appropriate reference line, the air is unstable.

To summarize the discussion on atmospheric stability, the following statements may be used:

1. A lapse rate that is less than the appropriate reference line produces a state of absolute stability.

2. A lapse rate that is parallel to the appropriate reference line produces a state of neutral stability.

3. A lapse rate that is greater than the appropriate reference line produces a state of absolute instability.

CONDITIONAL INSTABILITY

These examples regarding atmospheric stability are concrete and very easy to recognize; however, there exists within the atmosphere more frequently a state called "conditional instability" which is a bit more diffi-

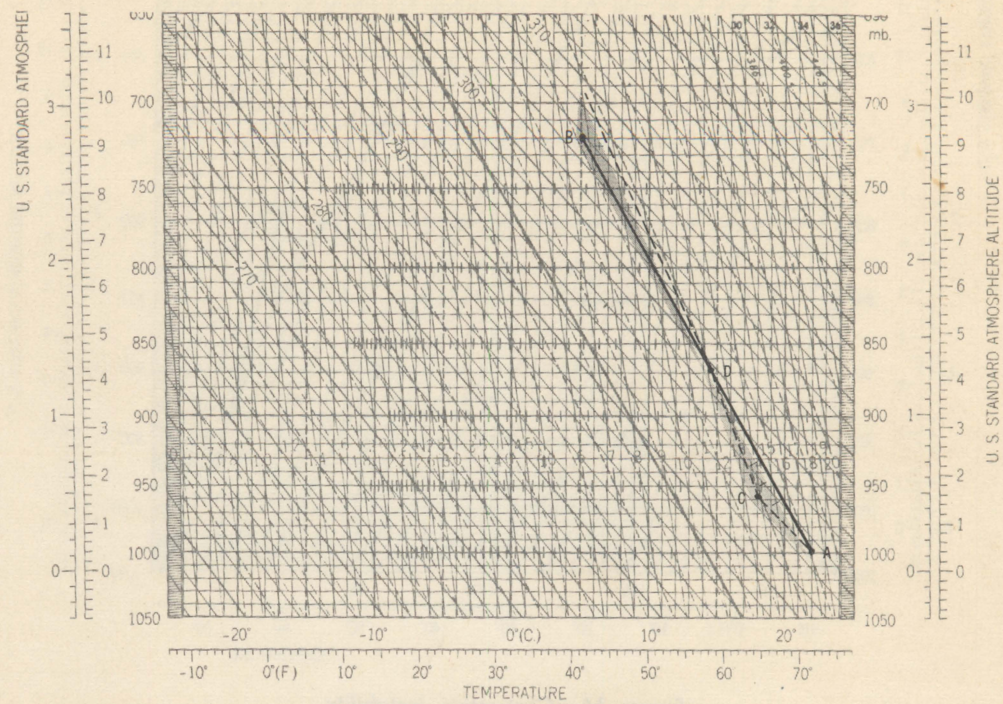


Figure 15—Conditional instability.

cult to analyze. This state involves a lapse rate which is greater than the moist lapse rate but less than the dry lapse rate. Provided that the moisture content of the column of air under consideration is just right and a parcel of air from this column is forced to ascend, it is possible for the situation to produce a state of instability.

The free-air curve in Figure 15 shows a lapse rate greater than the wet lapse rate but less than the dry lapse rate. The parcel of air at point A has a rather high relative humidity, and if lifted, would cool at the dry rate until it reached its saturation point. For purposes of this example, consider the saturation point to be at point C. If the parcel were lifted further, it would cool according to the wet lapse rate because the air is now saturated. If the lifting force carried the parcel beyond the point D, it would become warmer than the surrounding air and rise of its own free will. This would bring about a state of instability, as a result of the moisture content of the atmosphere and lifting by some mechanical means. This is the process used by the forecaster in determining the possibility of thunderstorms.

CONVECTIVE INSTABILITY

The last type of stability to be considered during this discussion is called convective instability and refers to instability that is a result of lifting of an entire layer of atmosphere with the proper moisture distribution. For example, notice what happens to an entire layer of air depicted by the free-air curve in Figure 16 when it is lifted.

Notice that the free-air curve in Figure 16 has a relative humidity of 100 per cent at the base, and a relative humidity of 50 per cent at the top. Consider that the relative humidity gradually decreases from the base to the top. In its present condition this layer of air is absolutely stable. In the process of lifting, however, this layer may become unstable. To show this, let us lift the entire layer a distance of 300 millibars. Throughout the lifting process the lower portions of the free-air curve cool according to the wet lapse rate, while the upper portions of the free-air curve

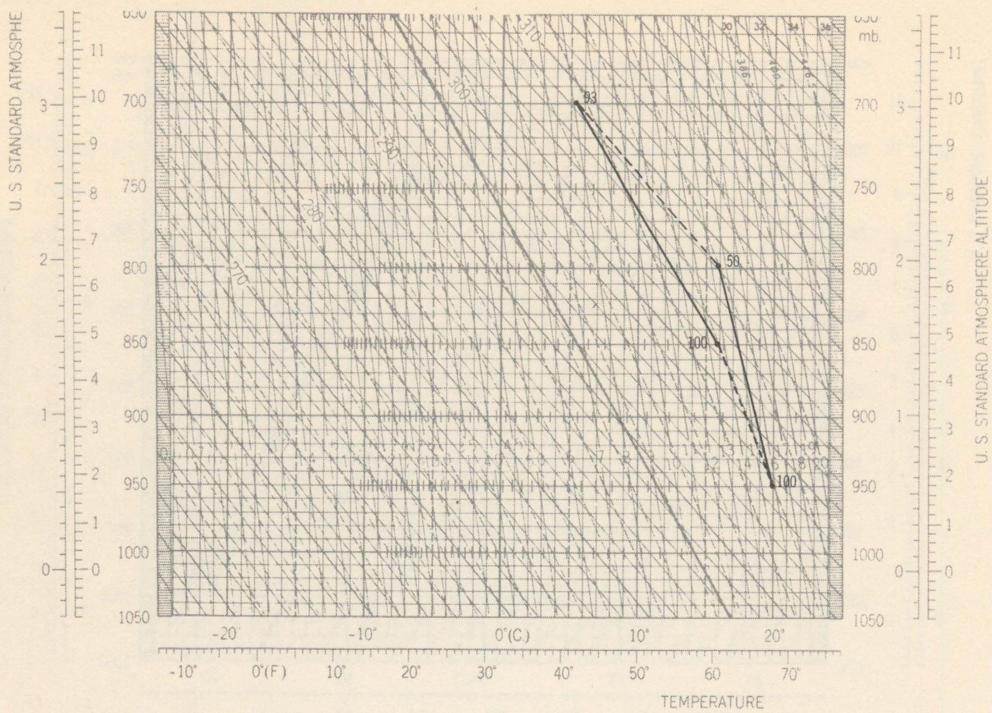
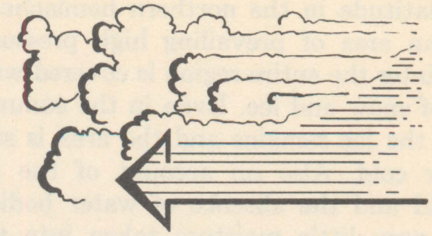


Figure 16—Convective instability.

cool according to the dry lapse rate. In so doing, the layer of air eventually has a slope to the left of the wet lapse rate line and the entire layer of air is wet, thus producing an unstable situation. This is said to be a convectively unstable layer of air. If the moisture distribution were reversed, with the dryest air in the lower portion of the layer and the moist air in the upper portion of the layer, then the entire layer would become more stable with lifting. This would then be called a convectively stable layer of air.

CHAPTER THIRTY



Air Masses

An understanding of the characteristics of an air mass is essential to any comprehensive study of weather phenomena in the temperate regions. The weather in these regions is a direct result of the continuous variation between the influence of warm and cold air masses. Warm air masses predominate in the summer and cold air masses predominate in the winter; but both cold and warm air, alternately, may prevail almost anywhere in the temperate zone at any season.

The basic characteristics of any air mass are humidity and temperature. These properties are relatively uniform throughout the horizontal extent of the air mass, and it is by measurement of these properties that the various types of air masses are determined.

DEFINITION

An air mass may be defined as any huge body of air whose physical properties (temperature and humidity) are horizontally uniform.

FACTORS WHICH DETERMINE CHARACTERISTICS OF AN AIR MASS

The properties of any air mass depend directly upon the type of surface over which the air is lying. Thus a knowledge of the type of surfaces over which the main bodies of air stagnate in the world circulation system offers a basis for a good comprehension of the air mass characteristics. These surfaces of origin are called source regions. They have a prime influence upon the characteristics of the air mass. The path over which the air mass travels after expanding and leaving the source region, and the length of time the air mass has been away from the source region (its age), also determine the characteristics of an air mass.

SOURCE REGION

The surface or region over which an air mass originates is called the "source region." It is in this region that the basic characteristics of the air mass are acquired. In order to fulfill the requirements for a good source region, an area must be of uniform surface (either all land or all water), uniform temperature, and preferably an area of high pressure where air has a tendency to stagnate. Some typical source regions may be analyzed in order to determine their general characteristics.

The CONTINENTAL POLAR SOURCE REGION consists of all the land area lying north of

the 60° latitude in the northern hemisphere. This is an area of prevailing high pressure. In the winter the entire region is covered with a layer of snow and ice. Even in the summer much of the ice remains and the area is still relatively cold. Also on account of the intense cold and the absence of water bodies, there is very little moisture taken into the air in this region.

The MARITIME POLAR SOURCE REGION consists of the open polar sea region north and south of 60° latitude in the northern and southern hemispheres respectively. These regions offer a considerable source of moisture for polar air masses. Air masses forming over these regions are moist, but moisture is limited by the temperature.

The CONTINENTAL TROPICAL SOURCE REGION can be any significant land area lying in the tropical regions, generally between 25° north and 25° south latitude. These large land masses in the tropical region usually manifest themselves as deserts, such as the Sahara or Kalahari of Africa, the Arabian Desert, and the entire region of inland Australia. The air lying over these regions is hot and dry.

The MARITIME TROPICAL SOURCE REGION is that vast zone of open tropical sea along the belt of the sub-tropical anti-cyclones north and south of the equator. Semi-permanent high-pressure cells stagnate over these regions nearly all year-round. The air here is warm by reason of the low latitude and is able to hold considerable moisture.

PATH OF AIR MASS AFTER LEAVING SOURCE

The source region has a very distinct influence on the shaping of the characteristic qualities of temperature and moisture for any given air mass, but certain other factors also act to change or modify these original qualities. As an air mass expands and slowly surges out of its source region to influence other regions, it moves along a certain *path.* The surface over which this path takes the air after leaving the source acts as an important modifier. For instance, a warm, moist body of air moves out over cold, dry land and its characteristics are modified. Moisture is lost, and temperature lowers.

THE AGE OF AN AIR MASS

Another factor which must not be overlooked in determining how an air mass is being changed or modified is the "age" of that body of air after leaving the source. For example, an air mass which has very recently moved from the source region will not have had time to become modified significantly; whereas an air body which has moved to a new region and stagnated for some time and is now old will be found to have lost many of its original qualities. It will have acquired many of the characteristics of the surface over which it now lies.

In summary then, it can be said that the characteristics of any air mass depend, first, upon the source region and, then, upon the trajectory and age of the air mass after leaving the source.

AIR MASS NOMENCLATURE

In order to study air masses and to analyze synoptic situations properly, it has been necessary to develop a standard system of air mass nomenclature. This system is based on the three principal characteristics of any uniform body of air, temperature, moisture, and stability.

Temperature

Temperature is indicated by the geographical position of the source region of the air mass; therefore, capital letters indicating the source region are used indirectly to indicate temperature. These are as follows: A—Arctic, P—Polar, T—Tropical, E—Equatorial. Of these, the two most commonly used in temperate zone weather analysis are P—Polar and T—Tropical.

Moisture

Moisture is indicated by a designation for the surface (land or sea) over which an air mass originates. A land source air mass is designated by the small letter c—continental, and a sea source air mass is designated by the small letter m—maritime. These small-letter

moisture designators precede the capital letter temperature designators. For example, cP indicates a continental-polar or (cold-dry) air mass.

Stability

An air mass moving out of its source region will be warmer than the surface over which it is flowing if it is moving north, or colder than the surface over which it is flowing if it is moving south. If the air is warmer than the surface, it will be cooled by contact with the cold ground and become more stable. On the other hand, if the air mass is colder than the surface over which it is moving, it will be heated from below and convective currents and instability will result. On weather maps these conditions are represented by letters. A small letter w indicates that the air is warmer than the ground over which it is flowing and thus stable. A small letter k is used to indicate that the air is colder than the ground over which it is moving and thus unstable. These small-letter designators follow the capital-letter temperature designators. For example, cPk indicates unstable, continental-polar or dry-cold, unstable air.

WEATHER TYPES

Because of the varying characteristics within the specific air masses, weather and flying conditions in one air mass are generally quite different from those in another. For this reason it is necessary that the pilot understand what type of weather to expect in any particular air mass. Because of the vast multiplicity of varying conditions involved, the discussion of air mass weather will be limited to the continental United States area.

Continental Polar Weather

Weather conditions in the cP air mass in the United States depend mainly upon the path the air mass takes as it pushes south out of its source. If the air mass expands in such a manner that the apparent *path* of its southerly motion is over any large water area such as the Great Lakes or Pacific Ocean, considerable moisture is added to the air. In the wintertime the water area presents a region of increased surface layer heating and furthers instability in these layers. The combination of moisture and additional instability produces rain or snow showers depending upon the temperature. On the other hand, if the southward path of this air mass is over land, there will be an absence of cloud forms because of the lack of moisture. Surface heating in the afternoon causes light turbulence and good visibility in the lower levels. At night, with no cloudiness, there is considerable radiation cooling in this air mass, a stabilizing effect in the lower levels, and a generally poorer visibility.

Maritime Polar Weather

Maritime Polar (mP) air in the United States is found almost exclusively on the west coast. In the wintertime this air which travels over the Northeast Pacific Ocean is colder than the water surface over which it travels southward. In this case it is heated from below and becomes convectively unstable to about 5,000 to 6,000 feet MSL. As this air flows inland, it is lifted by the coastal mountain ranges and showers and squalls result. Ceilings of 2,000 to 3,000 feet lowering to 1,000 feet in precipitation are common in this condition on the west coast. As this air crosses the mountains and flows eastward most of the moisture is extracted and relatively dry, stable air results. Flying conditions in this air mass east of the Rockies are generally the best in the United States in winter. There is little turbulence and yet good visibility except in industrial areas. Ceilings are generally unlimited. In the summertime, on the other hand, there is little or no heating in the lower layers as the air flows south eastward. The air approaches the continent as a fairly stable smooth air mass. As this stable air is lifted at the coastal ranges, stratus and fog result at northern and central west coast stations. After this air crosses the mountains, its characteristics are much the same as those of continental polar air.

Maritime Tropical Weather

Maritime tropical air of Atlantic origin is experienced in winter mostly in the southeast and Gulf States region. As this air flows northward, mild temperatures, high humidi-

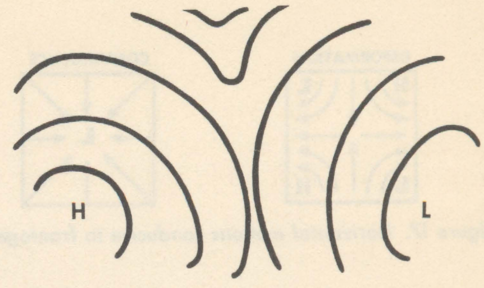
ties, and considerable cloudiness predominate as a result of the flow of moist air over the cool land surface. Stratus clouds form in the early morning and often tend to dissipate or "burn off" by noon.

As the Bermuda high cell expands in the summertime, nearly the entire east coast and all of the south-central United States comes under the influence of a continuous flow of mT air. This flow is broken only on very few occasions during the summer months. The air mass at this time is characterized by high temperature and high moisture content. Any lifting action, convective or orographic, sets off cumulus activity in the conditionally unstable air mass. Air mass and orographic thunderstorms are quite common at this season.

Continental Tropical Weather

Continental tropical air is found in the United States in the summertime only and, even then, only over the relatively small southwest desert area of southern Arizona, New Mexico, and west Texas. High temperatures and low humidities are the rule. Very little cloudiness is found. Considerable turbulence is often encountered in the afternoon in the very low levels (0—3,000 feet).

CHAPTER THIRTY-ONE



Frontal Weather

Ordinarily, the characteristics of the atmosphere change rather slowly from point to point. However, a large portion of extratropical weather phenomena is intimately associated with the existence of narrow zones in which the air characteristics change rapidly. These are transition zones between air masses, but for purposes of simplification, they are commonly referred to as lines of discontinuity or "fronts." One of the basic processes of the atmosphere is the process by which atmospheric discontinuities are brought about. This process is called "frontogenesis." The opposite process, by which this discontinuity is dissipated or destroyed, is called "frontolysis."

All atmospheric processes can be described mathematically and diagrammatically; however, it is not the purpose of this manual to prove the processes of the atmosphere mathematically, but rather to diagram and explain these processes for better understanding.

HORIZONTAL MOTIONS CONDUCIVE TO FRONTOGENESIS

Certain types of horizontal air motion have a strong tendency to bring air masses with dissimilar characteristics into adjacent positions conducive to the formation of fronts. Two types of atmospheric motion which favor this process are convergence and deformation. (See Fig. 17).

PRINCIPAL WORLD FRONTAL ZONES

The general circulation pattern and the average position of world pressure zones is such that certain areas in the circulation system are more conducive to convergence and deformation in air flow. The two main zones or belts in which these types of motion are most common are known as the "Polar Front" and the "Intertropical Convergence Zone." Most weather in the temperate latitudes is caused by outbreaks from the Polar Front. Most weather in the tropical regions is directly or indirectly a result of outbreaks on the Intertropical Front or Intertropical Convergence Zone (ITC). (See Fig. 18).

CLASSIFICATION OF FRONTS

The classification of all *fronts* is based upon the displacement of one air mass by another and the resultant temperature changes.

Cold Front

A cold front is a line along which cold air has displaced warmer air at the surface.

Warm Front

A warm front, on the other hand, is defined

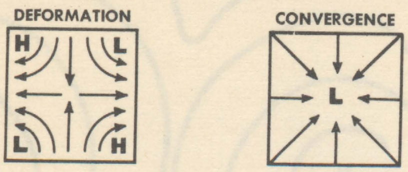


Figure 17. Horizontal motions conducive to frontogenesis.

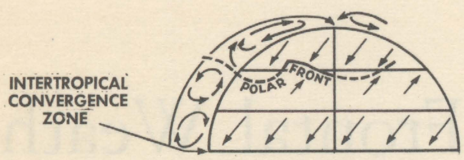


Figure 18. Principal world frontal zones.

as a line along which warm air has displaced colder air at the surface (Fig. 19).

Occlusion

The occlusion, although still embodying the same basic principles of air mass displacement stated above, is a more complex situation in which two fronts are involved. An occlusion is defined as a line along which a cold front has overtaken a warm front. Depending upon the comparative densities of the cold air masses involved, however, an occlusion may be classified as warm frontal type or cold frontal type. Picture a surface

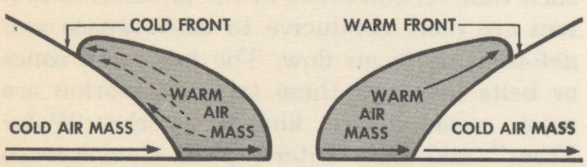


Figure 19—Cold front—Warm front.

cold front, oriented north-south on the weather map, overtaking a warm front oriented northwest-southeast. There will be three air masses involved; namely, the cold air mass behind the cold front, the cold air mass ahead of the warm front, and the warm air mass lying in the warm sector to the east of the cold front and south of the warm front (see diagram 20).

As the cold front overtakes the warm front, two of the three air masses must flow aloft over the third. This third air mass will have the greatest density. If the air behind the cold front is the most dense, it will wedge the warm

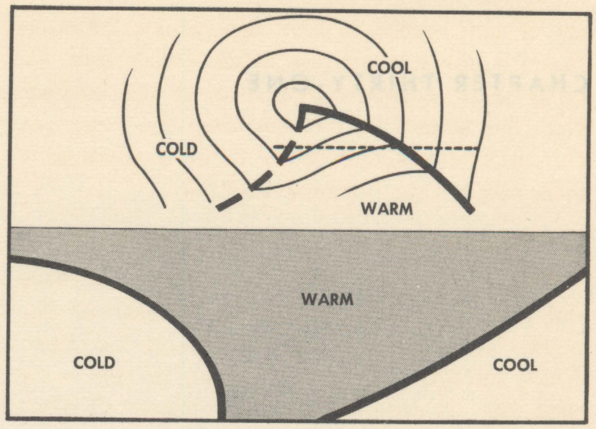


Figure 20—The Occlusion.

air aloft and then force the cold air ahead of the warm front aloft also (Fig. 21).

On the other hand, if it happens that the cold air ahead of the warm front is the most dense, then the entire cold frontal situation will rise over the slope of the cold air ahead of the warm front (Fig. 22).

In each case the type of resultant occlusion derives its name from the name of the front that remains at the surface. In the first case, we find that we have a cold-front type occlusion; in the second case, a warm-front type.

Stationary Front

The final frontal situation commonly encountered is the stationary front. As the name implies, there is no movement of air masses involved in this frontal type and, therefore, there is no actual displacement of

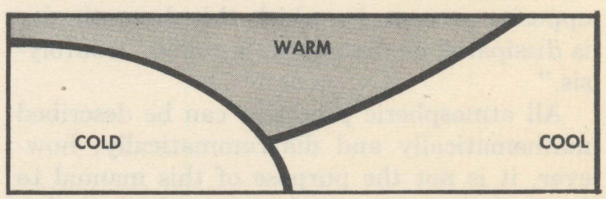


Figure 21—Cold type occlusion.

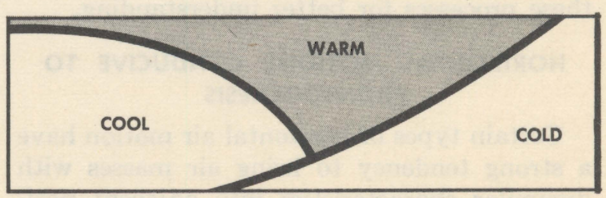


Figure 22—Warm type occlusion.

air at the surface. The stationary front is found when a warm air mass and a cold air mass lie in adjacent positions at the surface with the warm air overrunning the cold air. The surface position of the front is stationary with respect to forward motion.

INCLINATION OF FRONTAL SURFACES

The acute angle between a frontal surface and the ground is called the "slope" of the front. This slope would normally be horizontal as oil and water placed in the same container; it varies from the horizontal, however, because air masses as well as the earth are continually in motion. In reality, the slope of a frontal surface is so shallow that even in the case of a steep cold front the degree of inclination, or slope, varies only about 3° from the horizontal. A fast moving warm front may have a slope of 400 to 1. This means that 400 miles from the place where the front meets the ground, the frontal surface would be 1 mile above the earth. Thus, the variation of the frontal slope from the horizontal is only very slight. The angle of inclination of the front is considerably less than 1° (See Fig. 23).

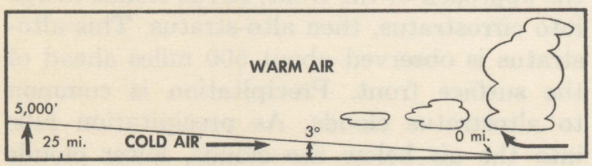


Figure 23—Slope of a Steep Cold Front (1:25).

The actual degree of inclination of any front depends upon the speed of motion of the front. As a cold front travels toward the warm air mass more rapidly, the slope increases. The amount of increase in slope of a cold front is directly proportional to the speed of the front. This is due to the fact that a frontal surface moves with the component of the relative wind normal to the front at or above the gradient level. Wind velocity increases with height as in the case of a fast moving cold front. Therefore, it should be readily seen that the surface of discontinuity will move faster aloft than at the surface, thus steepening the cold frontal slope (Fig. 24).

In the case of the warm front, the more rapidly the warm air mass moves toward the cold air mass, the shallower the frontal slope becomes. In this case, again, the frontal surface aloft is moved with relative winds aloft of greater velocity than those near the surface. Thus, it is seen that the greater the forward speed of the warm front, the shallower the slope becomes (Fig. 25).

The average cold frontal slopes are about 1:50 to 1:150 and that average warm frontal slopes are about 1:250 to 1:300. This means that a cold front which has a frontal surface extending fifty miles back over the cold air is one mile (or 5,280 feet) high at that point, and so forth.

DISCONTINUITY OF CHARACTERISTICS ACROSS A FRONT

The characteristic properties of an air mass differ from those of another. Some of these characteristics which become discontinuous at the frontal surface, and identify the frontal position, are temperature, wind direction, pressure tendency (or direction or change in the last 3 hours), and dew point (which is related to, but more constant than temperature).

Temperature

One of the most obvious and most easily recognizable discontinuities across a frontal surface is temperature. Since all fronts consist of warm air overrunning the cold air, any radiosonde flight through a frontal surface shows a temporary relative temperature in-

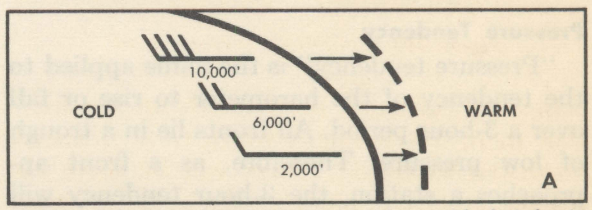


Figure 24—Wind velocity increasing with height in cold air causes front to steepen.

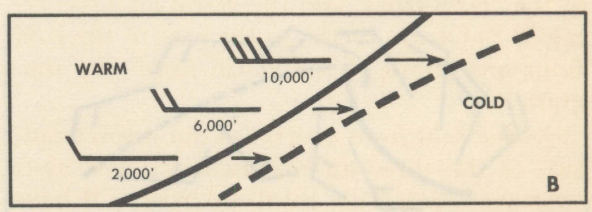


Figure 25—Wind velocity increasing with height in warm air causes slope to become shallower.

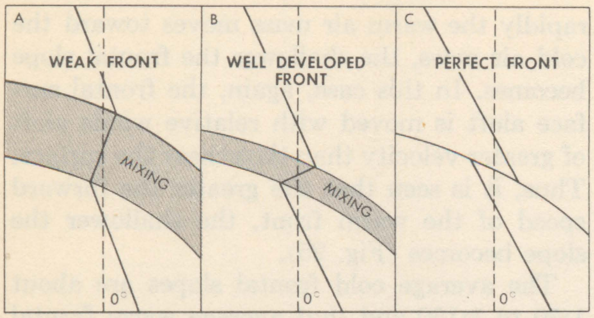


Figure 26—Soundings through frontal surfaces.

crease indicating the warm air aloft. This is the frontal inversion. The width of this inversion indicates the degree of development of the front. (See Figure 26).

Discontinuity of temperature is also noted between two adjacent ground stations between which the front is lying. The station in the cold air mass has a colder temperature, representative of all stations in the cold air mass, while the station in the warm air mass has a warmer surface temperature, representative of all stations in the warm air mass.

Wind

A front is generally recognized as a windshift line. The wind must shift cyclonically across the frontal surface. Many times a frontal passage at the earth's surface may be recognized not only by a wind shift but also by a notable change in wind speed. In most cases wind speed increases abruptly just after a cold frontal passage. (Figure 27).

Pressure Tendency

"Pressure tendency" is the name applied to the tendency of the barometer to rise or fall over a 3-hour period. All fronts lie in a trough of low pressure. Therefore, as a front approaches a station, the 3-hour tendency will show a continuous fall in pressure. As soon

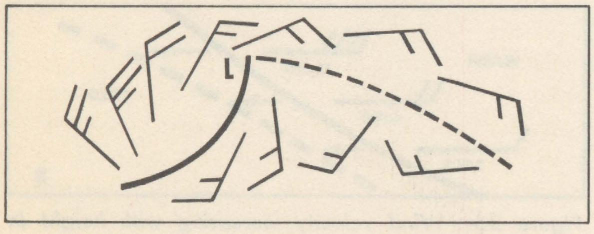


Figure 27—Circulation in a frontal situation.

as the front passes the station, the tendency will show an abrupt rise and then a continuous rise in pressure. It should be noted that pressure alone is no index of frontal passage, but that change in pressure with time, called pressure tendency, is an excellent index.

Dew Point

The dew point is that temperature at which the air may no longer take on moisture or that temperature at which the air is saturated. As an index of frontal passage, a dew point is excellent because it is more constant than temperature through the day and is not greatly affected by daily heating and cooling of the earth's surface.

WARM FRONTS

In the warm front the velocity of warm air normal to the front is usually greater than the velocity of the retreating cold air. Therefore, there is always a continuous upglide of warm air up over the cold air. The general pattern of clouds are first observed 750 to 1,000 miles ahead of the warm front. These clouds are in the warm air above the frontal surface. With the approach of the front, cirrus clouds merge into cirrostratus, then alto-stratus. This altostratus is observed about 500 miles ahead of the surface front. Precipitation is common to altostratus clouds. As precipitation falls into the air below the clouds, lower clouds begin to form from evaporation of the warm raindrops, increasing the moisture content of the cold air to its saturation point. This causes several layers of stratus clouds, a condition common to most all warm fronts. These stratus decks may even form on the surface as fog. In many instances the warm air may be convectively unstable and showers and thunderstorms may be superimposed upon this general warm front picture. This, of course, creates an additional hazard since the predominance of stratus often obscures the thunderstorms, and pilots may find extreme turbulence, hail, and other thunderstorm hazards where they are least expected.

COLD FRONTS

In the cold frontal situation cold air dis-

places warm air at the surface. There are two types of cold fronts, active and inactive.

Active Cold Fronts

Active-type cold fronts are generally observed outside of the zone of cyclonic activity. They are generally slow moving and sometimes even stationary. The cloud system which resembles that of a warm front is followed by altostratus and cirrus clouds. The slope of this type of cold front is generally about 1:100, but is considerably steeper near the surface because of friction. As the unstable, moist warm air is lifted abruptly over the relatively steep surface slope, cumulus build-ups, showers, and thunderstorms result. Descending air in the cold air behind the front usually prevents formation of many clouds behind the front. Vertical soundings through this type of cold front show pronounced inversion, clear-cut discontinuity of temperature and high relative humidities. This type of cold front is referred to as "active", not because of any extreme degree of turbulence or vertical motion, but because the weather is generally concentrated in a band along the actual surface position of the front (Figure 28).

Inactive Cold Fronts

When advancing cold air forces a front to move ahead of it, the front is called a cold front. Since a cold front must move with nearly the speed of the cold air mass, being the forward surface of that mass, a cold front usually moves faster than a warm front. Friction deforms the frontal surface by retarding the layer of air near the ground. This causes the frontal slope to be steeper than is usual for a warm front. The slope of a cold front is usually 1 in 50 to 1 in 100, and near

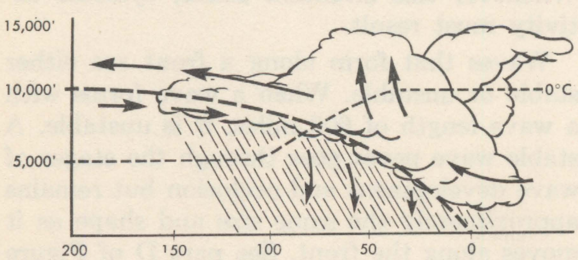


Figure 28—Circulation and cloud forms in cross section of active front.

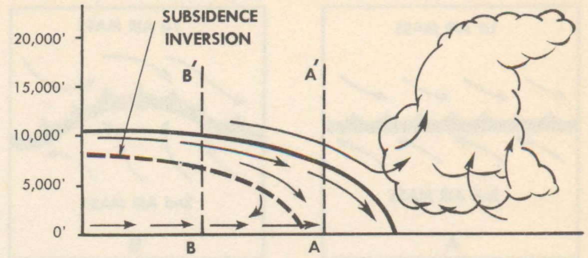


Figure 29—Inactive cold front.

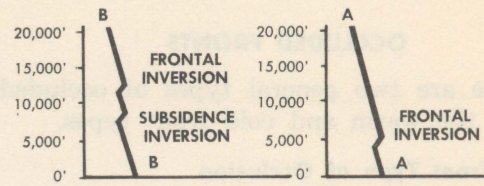


Figure 30—Soundings through points B-B' and A-A'.

the ground is occasionally much steeper than that. The type of clouds and severity of the weather encountered depends upon the stability of the warm air mass. If the warm air mass is stable, a narrow band of thick clouds with some rain or snow is formed. Ceiling visibility may be very low in the immediate zone of the front, but good weather prevails a short distance away in either air mass, unless other forces form to complicate the picture.

If the warm air mass is conditionally unstable, a narrow band of very active cumuliform clouds forms along, and a short distance ahead of, the cold front in the warm air. The larger of these clouds are cumulonimbus (thunderstorms), and they may stand side by side in a line along the front forming an almost impenetrable wall of turbulent clouds. This occurrence is called a line squall.

Behind a cold front, the cold air near the ground is rapidly heated and usually moistened from below. Hence it is unstable, resulting in bumpy flying; a deck of strato-cumuliform clouds is usually found. This cloud deck becomes broken and scattered at a distance from the frontal zone. Bands of dissipating alto-cumulus clouds commonly exist on the upper portion of the frontal surface. This type of front is referred to as inactive, since the actual weather forms ahead of the surface position of the front in the warm air mass and not at the front proper (Fig. 29 and 30).

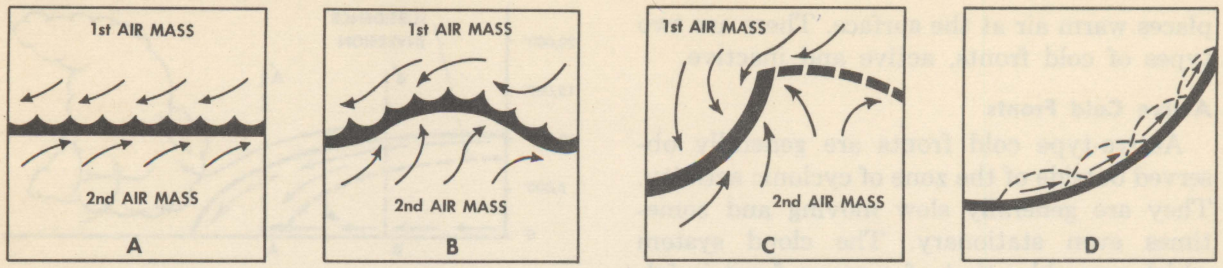


Figure 31—Stable wave formation.

OCCLUDED FRONTS

There are two general types of occluded fronts, the warm and cold front types.

Warm Front Type of Occlusion

In the warm front occlusion, the cold air under the slope of the warm front is denser (colder) than the air behind the advancing cold front; hence, the cold front rises over the warm front just as the warm air does. The weather in this type of phenomenon is generally a combination of warm and cold front weather. The showers and cumulus activity of cold front are blended in with the expansive stratus formations of the typical warm front. Shower activity and heavy intermittent rain are superimposed on the steady precipitation pattern of the warm front.

Warm-type occlusions are common on the west coast of continents where the cold air, moving on shore, is usually warmer than the cold air under the slope of the warm front.

Cold Front Type of Occlusion

In this type of front, the air behind the cold front is the denser of the two, and as the cold front overtakes the warm front, the air behind the warm front is forced to rise. The weather is much the same as general cold front weather inasmuch as the cold front remains at the surface. The stratus clouds, however, extend far out ahead of the cold front weather in very much the same manner as in the common warm front.

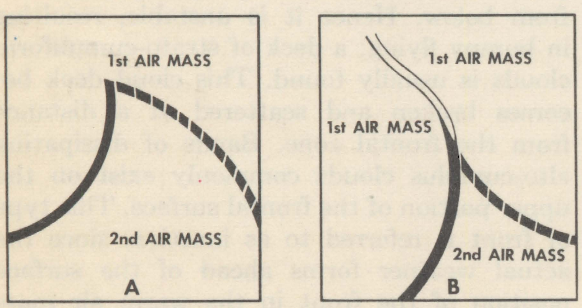


Figure 32—Unstable wave formation

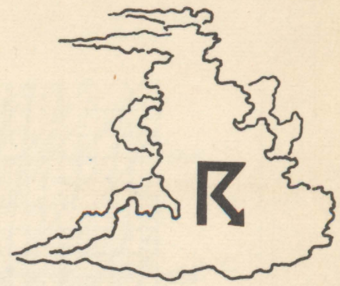
WAVE FORMATION ALONG FRONTS

As one air mass moves to displace another, a front is formed. The front is the boundary line between the two air masses. Since most major air masses consist of high-pressure cells with anticyclonic circulation, there is a wind shear or cyclonic wind shift across the front. This is shown in part A of Figure 31.

Along this shear line an eddy sets up by the opposing motions as may be seen in part B of Figure 31. As this eddy motion is set up, the logical sequence is for a wave to form much in the same manner as waves form along the surface of two discontinuous masses, such as air and water. In part C a wave has formed and is recognizable as similar to those waves so often seen on surface weather charts. The direction of air flow in this eddy or wave is no longer clockwise as in the case of the circulation within the air mass, but counterclockwise or cyclonic. A cyclone, then, is nothing more than the effect of two air masses brought together and separated by a front. Whenever this situation exists, cyclonic activity must result.

Waves that form along a front are either stable or unstable. When a wave forms with a wave length of 600 miles, it is unstable. A stable wave never goes through the stages of wave development and occlusion but remains approximately the same size and shape as it moves along the front. See part D of Figure 31. Unstable wave development is shown in Figure 32.

CHAPTER THIRTY-TWO



Thunderstorms

GENERAL

The pilot of today's Air Force must be capable of reaching his destination, or objective, regardless of weather conditions en route. Since 44,000 thunderstorms occur daily over the surface of the earth, a pilot will be forced to fly through a thunderstorm, or a thunderstorm area, at some time or another. Thunderstorms present a hazard, but flight through one should be looked upon as being neither heroic nor superhuman. It is the responsibility of every pilot to be able to plan and conduct a flight through an area of turbulence and associated phenomena with the same knowledge and confidence as for any other weather situation. In order to do this, he must be cognizant of the problems presented by thunderstorms.

The normal person is subject to a psychological hazard, fear of the unknown. This particular hazard cannot be taken lightly. Fear and anticipation often make a person incapable of using the skill and training he has had. When this occurs, he is no longer responsible for his actions. In order to prevent this situation from occurring, it is necessary to understand why a person is subject to fear and what can be done to prevent it. Fear is aroused by events for which a person has no immediate practical response other than to shrink or flee (panic). Such events range from sudden or intense stimuli, for which the body is unprepared, to situations in which a person recognizes a real or imagined danger. Forewarning helps to forestall fear of a new situation, and even more helpful is the procedure of initiating a person into the situation gradually rather than precipitously. Therefore, in order to conquer this hazard, the pilot must thoroughly understand the physical makeup of thunderstorms.

Early in 1946 a joint project of the Air Force, Navy, National Advisory Committee for Aeronautics, and the Weather Bureau, was initiated in order to meet the urgent need for information on thunderstorms. This organization was named "The Thunderstorm Project." A great part of the following information has been made available as a result of the diligent efforts of the personnel of this project.

FACTORS NECESSARY FOR THUNDERSTORM FORMATION

A certain combination of atmospheric conditions is necessary for the formation of a

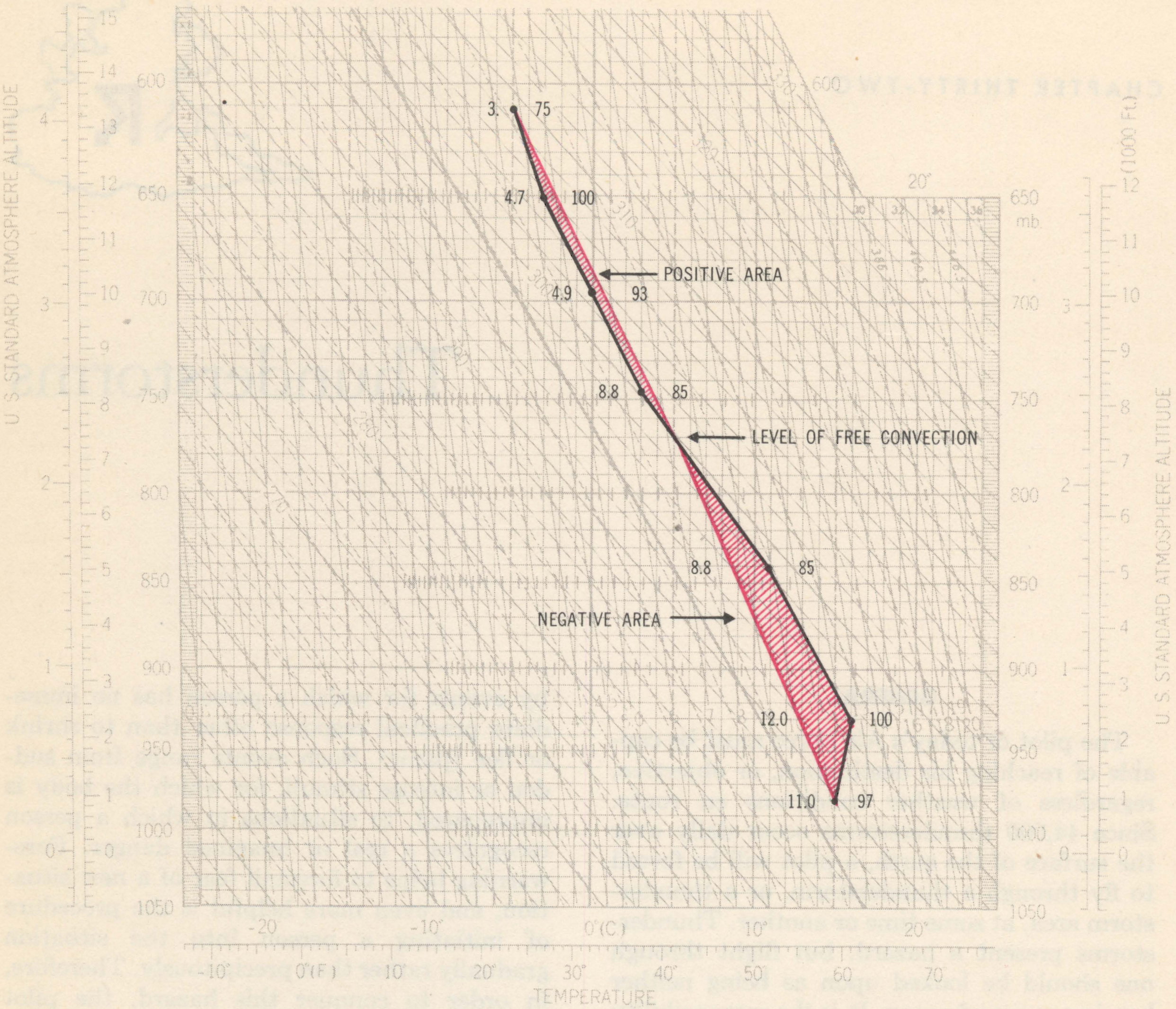


Figure 33—Unstable sounding.

thunderstorm. These factors are conditionally unstable air of relatively high moisture content, and some type of lifting action.

Conditional instability exists when the lapse rate of the air involved lies between the wet and dry reference lines on the standard Adiabatic chart. Before the air actually becomes unstable, it must be lifted to a point where it is warmer than the surrounding air. When this condition is brought about, the relatively warmer air continues to rise freely until, at some point aloft, its temperature has cooled to the temperatures of the surrounding air. In the following diagrammatic explanation of the instability process numerous variables, which tend to modify the size of the positive and negative areas, are omitted. One of the most important of these variables is the process called "entrainment" in which adjacent air is carried upward or downward by the rising drafts or by the falling rain. This entrained air has a modifying effect upon the temperatures of the air within the storm.

Lifting Action

In order to bring the warm surface air to the point where it will continue to rise freely (the level of free convection) some type of external lifting action must be introduced.

Many conditions will satisfy this requirement. For example, a front will lift warm air aloft to the level of free convection. (Figure 33).

Moisture

Warm air lifted upslope does not always set off free convection. It is possible to lift air to a point where the moisture condenses and forms clouds, but these clouds will be stable in nature if the level of free convection could not be attained by this lifting. Conversely, it is possible for dry, heated air to rise convectively without the formation of clouds. In the latter condition, turbulence might be experienced in perfectly clear weather. In order for a cumulus-type cloud to form, then, a combination of *unstable air*, *some type of lifting action*, and *high moisture content* is necessary.

TYPES OF THUNDERSTORMS

All thunderstorms are similar in physical makeup, but for purposes of identification are divided into two general groups: frontal thunderstorms and air-mass thunderstorms. This gives the pilot a reference as to the method by which the storms are formed. The key to the specific nomenclature of these lies in the manner by which the lifting action occurred.

Frontal Thunderstorms

These can be subdivided into three types, each having certain general characteristics.

The Warm Front Thunderstorm

This thunderstorm is caused when warm, moist, unstable air is forced aloft over a colder, denser shelf of retreating air. Owing to extreme shallowness of the warm frontal slope, the air is lifted gradually. The lifting condensation level is reached long before the level of free convection, with stratus conditions generally resulting. If the level of free convection is reached, however, warm-front thunderstorms form. The level of free convection will normally be reached at isolated points along the lateral surface of the front aloft, and, therefore, warm-front storms are generally scattered. Warm-front storms are extremely difficult to identify because they are obscured by other clouds. The warm front is dangerous because the pilot may be taken unaware and fly from an area of relatively smooth instrument flight into an area of great turbulence in a matter of seconds. A thorough study of the appropriate upper-air soundings, along the proposed route of flight, often aids the pilot by forewarning him of the existence of an unstable lapse rate.

The Cold Front Thunderstorm

This thunderstorm is caused by the forward motion of a wedge of cold air into a body of warm, moist, unstable air. The slope of a cold front is relatively steep, which causes the lifting condensation level and the level of free convection to be near the same level. Cold-front storms are normally positioned along the frontal surface aloft in what appears to be a continuous line. The problem of recognition is negligible in that most cold-front storms are partly visible to the pilot approaching from the front or rear. The vertical extent of a storm is governed, to a certain extent, by the height of the freezing level. Bases of these storms are usually close to the surface.

Prefrontal or Squall Line Thunderstorms

These are associated with, and form in advance of, a cold front. When a condition exists that allows the air above the front to exceed the velocity of the air below, downslope motion occurs. As this mass of cold air aloft progresses into the warm air, the downslope motion becomes more intense because of the greater density of the cold air. As the cold air subsides, the warm air in the trough converges, and when proper conditions are present, thunderstorms result. In general, the storms caused by this activity are in advance of the front. Prefrontal storms are usually intense and appear very menacing. Bases are very low. A pilot approaching such a line of storms may think that he is approaching the front. Tornadoes are not uncommon when this type of activity is present.

Air-Mass Thunderstorms

There are three types of air mass thunderstorms, and all have two things in common. They form within an air mass and they are

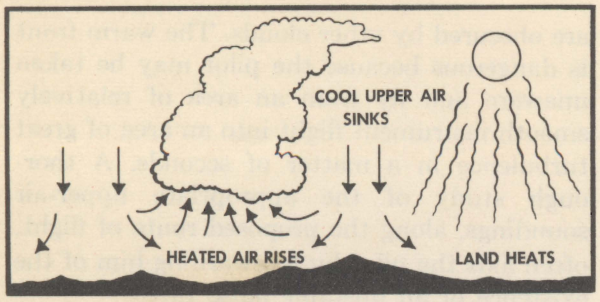


Figure 34—Convective thunderstorms.

generally isolated or scattered over a large region.

The Convective-Type Thunderstorm

This thunderstorm may occur almost anywhere in the world, over land or water. Formation is caused by solar heating of various areas of the land or sea, which in turn provides heat to the air in transit. The land type convective thunderstorms normally form during the afternoon hours after the earth has gained the maximum heating from the sun. If the circulation is such that cool, moist, convectively unstable air is passing over this land area, heating from below will cause convective currents and result in towering cumulus or thunderstorm activity (see Figure 34). Dissipation normally occurs during the early morning hours after the land has lost its heat to the atmosphere. Those storms that take place over bodies of water form in the same manner but at different hours. The general hours of formation for sea storms are during the evening hours after the sun has set. They dissipate during the late morning hours. An example that combines both is the situation that exists in Florida. Circulation around the Bermuda high transports moist air over the land surface of Florida during the entire day. The flow is from the west across the peninsula. During the hours of sunlight, the land surface is considerably warmer than the air; consequently, the air is subject to heating from below. Convective currents result, and the common afternoon thunderstorm is observed. After sundown the earth loses its heat and dissipation occurs, and the apparent movement of the storms out to sea takes place. As the circulation causes air to flow over the peninsula at night, the air is cooled by the land surface. As this same air moves out over the warm water of the Gulf Stream, it is heated from below, and cumulus activity occurs. Water is not subject to such rapid temperature changes as is land, and therefore does not retain much of the heat gained during the day. When the sun rises, the air over the sea surface becomes warmer, thereby destroying the balance necessary to keep a storm active, and dissipation occurs. As a general rule, convective-type storms are scattered and easily recognized; they are relatively high and visibilities generally excellent in the surrounding area. (See Figure 35).

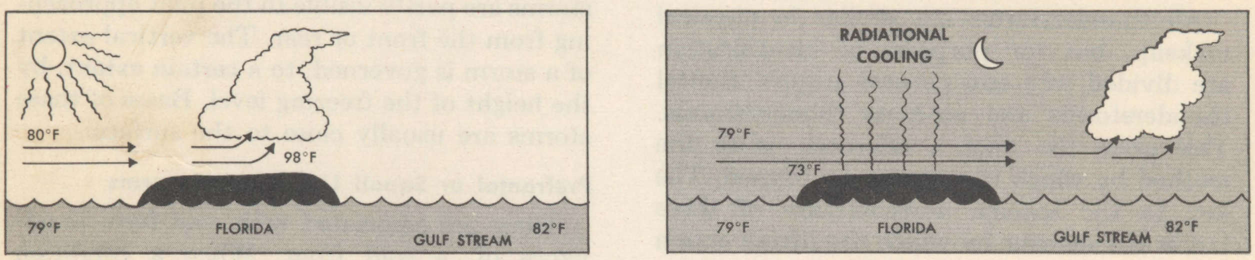


Figure 35—Convective-type thunderstorms of Florida.

Orographic Thunderstorms

As the name implies, these storms form in mountainous regions, particularly adjacent

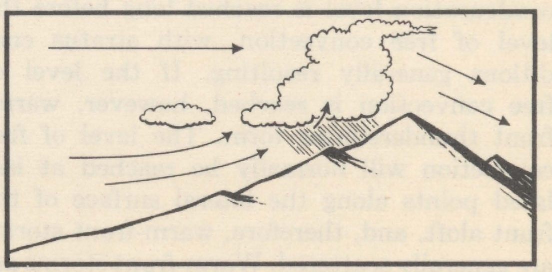


Figure 36—Orographic thunderstorm.

to individual peaks. A good example of this is shown in the northern Rocky Mountain region. When the circulation of the air is from the west, moist air from the Pacific Ocean is transported to the mountains and there it is forced aloft by the upslope of terrain. If the air is also conditionally unstable, this upslope motion causes thunderstorm activity on the windward side of the mountains. This activity may form a long unbroken line of storms similar to a cold front. The storms persist as long as the circulation causes upslope motion. From the windward side of the mountains, identification of orographic storms may sometimes be difficult on account of obscurement by other clouds, usually stratus type. From the lee side, identification is positive; the outlines of each storm are plainly visible. It is not advisable to fly through them. This type storm almost without exception enshrouds a mountain peak or a hill. No attempt should be made to fly under this storm unless the opposite side of the area is clearly visible to the pilot. (Fig. 36).

STRUCTURE OF THUNDERSTORMS

The fundamental structural element of the thunderstorm is the unit of convective circulation known as a convective cell. A mature thunderstorm contains several of these cells varying in diameter from one to five miles. By radar analysis and measurement of drafts, it has been determined that the cells are generally independent of surrounding cells in the same storm. Each cell progresses through a cycle lasting from one to three hours. In the initial stages of cumulus development, the cloud consists of a single cell, but as the development progresses new cells form and older cells dissipate. The life cycle of the thunderstorm cell consists of three distinct stages: (1) the cumulus stage, (2) the mature stage, and (3) the dissipating or anvil stage.

Cumulus Stage

The common cumulus cloud is the basis for all thunderstorms. Actually, only a very small percentage of cumulus clouds ever become thunderstorms, but this activity always pre-

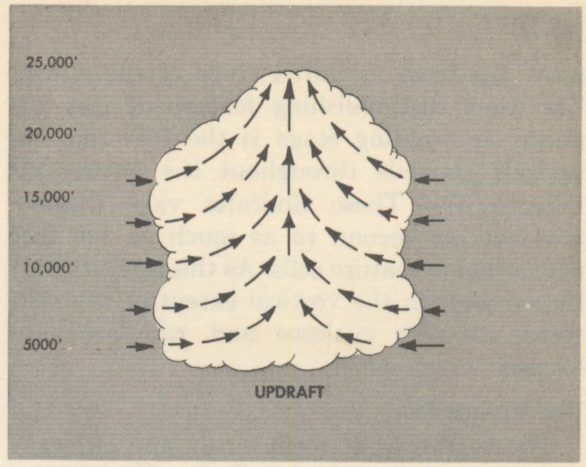


Figure 37—Typical cell in the cumulus stage.

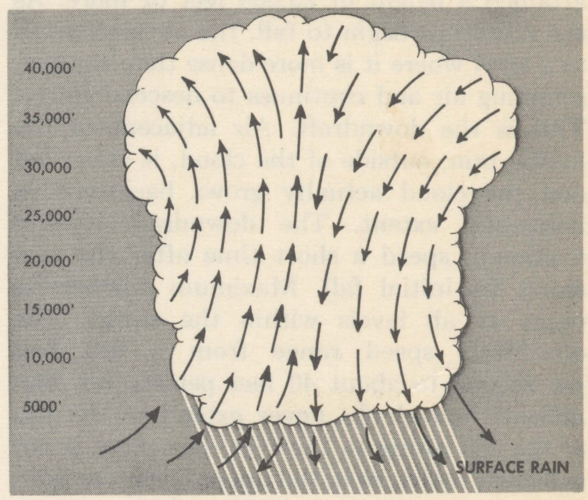


Figure 38—Typical cell at mature stage.

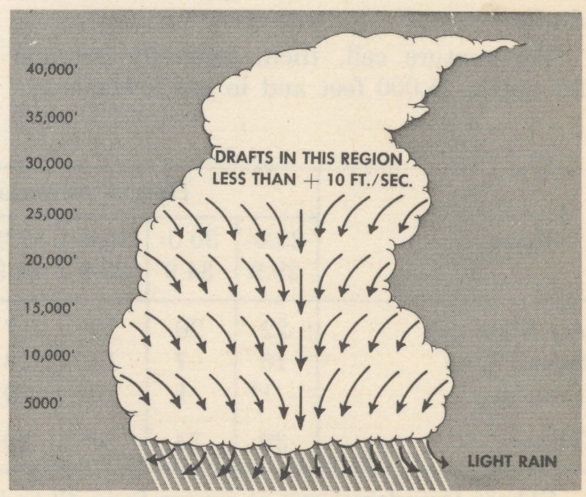


Figure 39—Cell in the dissipating stage.

sents the basis or initial stage of the storm. The chief distinguishing feature of this cumulus or building stage is the fact that an updraft prevails throughout the entire cell (Figure 37). These updrafts vary from a few feet per second to as much as 100 feet per second in mature cells. As this updraft continues through the vertical extent of the cell, water droplets coalesce and raindrops are formed.

The Mature Stage

The beginning of surface rain and adjacent updrafts and downdrafts (Figure 38) initiates the mature stage. By this time the cell has attained a height of 25,000 feet or more. As the raindrops begin to fall, the air aloft sinks to a level where it is more dense than the surrounding air and continues to descend freely. This is the downdraft. Air adjacent to the falling rain, outside of the cloud, is saturated and the cloud actually grows backward in horizontal extent. The downdraft reaches maximum speed a short time after the rain starts its initial fall. Maximum downdrafts occur at all levels within the storm. The downdraft speed range from a few feet per second to about 40 feet per second. Significant downdrafts never extend to the top of the cell owing to the fact that there is not sufficient moisture in the upper levels for raindrops to form. At these levels only ice crystals and snowflakes are present and their rate of fall is insufficient to cause appreciable downdrafts.

The mature cell, then, generally extends far above 25,000 feet and in the lower levels consists of sharp updrafts and downdrafts adjacent to each other. Above, only updrafts exist. Large water droplets are encountered suspended in the updrafts and descending with the downdrafts as rain.

Dissipating or Anvil Stage

Throughout the life span of the mature cell, more and more air aloft is being dragged down by the falling raindrops (Figure 39). Consequently, the downdraft spreads out to take the place of the dissipating updrafts. As this process progresses, the entire lower portion of the cell becomes an area of downdraft. Since this is an unbalanced situation, and since the descending motion in the downdraft effects a drying process, the entire structure now begins to dissipate. The high winds aloft have now carried the upper section of the cloud into the familiar anvil form, indicating that gradual dissipation is overtaking the storm cell.

VERTICAL DEVELOPMENT

The height of storms are of chief concern to pilot personnel whose responsibility is to determine an optimum flight altitude. Prior to the advent of radar analysis, it has been difficult to give accurate estimates of cumuliform cloud tops because of the general presence of stratified clouds in the lower levels.

Measurements of the vertical extent of thunderstorm activity were made by personnel of the Thunderstorm Project by using radar equipment with a range-height indicator (RHI). The closest correspondence between the radar-measured top and the actual top occurs during the cumulus stage.

Type	Height (thousands of feet)							Mean Height 1000 ft.	No. Days	No. Storms
	25.0-29.9	30.0-34.9	35.0-39.9	40.0-44.9	45.0-49.9	50.0-54.9	55.0-59.9			
Air Mass	22	26	19	17	14	11	2	37.2	5	111
Squall Line	16	7	15	13	11	8	0	37.7	5	70
Frontal	1*	1	0	0	2*	0	0	37.8	1	4
Total	39	34	34	30	27	19	2	37.4	11	185

*These thunderstorms at ranges from 43 to 56 miles.

Figure 40—Frequency Distribution of the Maximum Vertical Extent of Thunderstorms Detected by AN TPS-10

Measurements of the maximum vertical extent of various types of storms were made by radar. Height distribution frequency was observed as shown in Fig. 40.

This chart shows that, of the storms observed, those of the greatest vertical extent were of the air mass variety. The few frontal storms observed appeared to be the least in vertical extent. Storms of heights of 50,000 feet or over were measured in less than 10 per cent of the cases observed. The greatest frequency of storms measured had heights between 25 and 29 thousand feet. The average of all heights measured was 37,000 feet, and the maximum height observed was 56,000 feet.

DRAFTS AND GUSTS

Any discussion relating to the physical structure of a thunderstorm must include a section pertaining to drafts, for rising and descending drafts of air are, in effect, the structural basis of the thunderstorm cell. A draft is a large scale vertical current of air continuous over many thousands of feet of altitude. Speeds of the drafts are either relatively constant, or vary only gradually from one altitude to the next. Gusts, on the other hand, are smaller scaled discontinuities associated with the draft proper. Individual gusts have only a very short horizontal and vertical extent, but it is these gusts which actually cause the severe bumpiness so common to the cumuliform cloud. A draft may be compared to a great river flowing at a fairly constant rate, whereas a gust is comparable to an eddy or any other random motions of water within the main current.

Drafts

Considerable data on drafts have been collected and tabulated by project personnel and certain very definite conclusions can be made. Measurements of drafts were made by computing changes in pressure altitude. No effort should be made by the pilot to maintain altitude during the measurements.

Some of the findings are as follows:

1. The maximum updrafts were measured in the middle and upper levels flown.

2. Mean updraft and downdraft velocities increase with height.

3. Updrafts were generally of greater velocities than downdrafts.

Certain data have also been made available regarding aircraft displacement as a result of drafts. Some of the more important of these points are:

1. Greater aircraft displacement was observed at the higher levels. An airplane flying at 150 mph suffered a displacement as great as 6,000 feet in the upper levels of the storm cell, whereas similar aircraft flying at the same air speed at the 6,000-foot level experienced maximum displacement of only 1,600 feet.

2. In the middle and upper levels of the cell, mean displacement caused by updraft was greater in all cases than mean displacement caused by downdraft. Therefore, flight through storms in the middle and upper levels will result in a gain in altitude.

3. In no case was an aircraft, while flying at the 5,000- or 6,000-foot level, brought dangerously close to the ground by a downdraft (uneven terrain areas excepted).

4. At all levels, with the exception of the 6,000-foot altitude, the mean upward displacement was greater than the mean downward displacement.

It is evident from the preceding data that the pilot, at least, has the odds in his favor regarding general terrain clearance in most thunderstorms.

Gusts

Turbulent motions (gusts) within the cellular circulation pattern of thunderstorms have a considerable effect upon an aircraft. In fact, the actual severity of a storm is dependent upon the intensity and frequency of these gusts. Many enlightening statistics have been gathered regarding gusts. The lower gust speeds (2 to 10 ft. sec.) are far more frequent at all altitudes than are those of higher velocity; but the high velocity gusts (24 ft. sec. and greater) were also observed at all altitudes, though far less frequently. Since gusts of all speeds are prevalent at

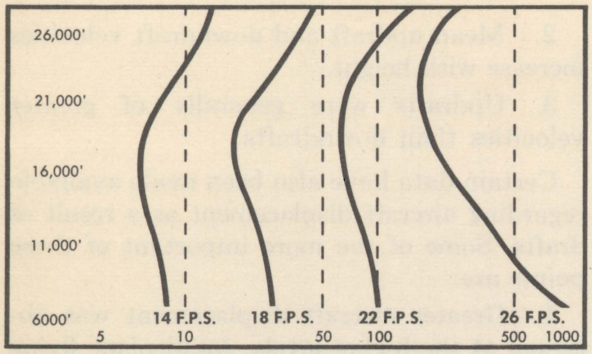


Figure 41—Miles of flight (logarithmic scale).

Miles of flight necessary in thunderstorm conditions to encounter a maximum effective gust velocity greater than indicated.

all altitudes, it must be determined from the statistics those altitudes at which the higher velocity gusts are found most frequently; for these create the greatest structural hazard. Figure 41 shows that there is a definite maximum frequency of the higher speed gusts in the vicinity of 15,000 feet near the freezing level.

In Figure 41 the curves are generally skewed to the left at 16,000 feet and farthest to the right at 6,000 and 26,000 feet, showing the greatest frequency of gusts of given speed (especially those of higher velocity) at the 16,000-foot level and the least frequency at the extreme upper-and lower-altitude limits.

Gusts as high as 43 ft. sec. have been measured during thunderstorm penetrations. Most aircraft are built to withstand the stress imposed by a gust of this nature, provided the air speed is sufficiently low at the time such gusts are encountered. High speed gusts have been known to cause permanent set and even structural failure, but in most of these cases, it is believed that the high gusts were encountered at the higher air-speed limits. Since the greatest frequency of higher speed gusts was observed at the 16,000-foot level, it is well to avoid this level when thunderstorm penetration becomes necessary; however, this does not mean that high gusts are not encountered at other altitudes.

WEATHER WITHIN THE STORM

Rain

The pilot, upon entering any thunderstorm, may expect to encounter considerable quantities of liquid moisture which may not necessarily be rain. Liquid water in a storm may be ascending if encountered in a strong updraft; it may be suspended, seemingly without motion, yet in extremely heavy concentrations; or it may be falling to the ground. If it is falling, it is rain in the true sense of the word. Rain, as normally measured by surface instruments, is associated with the downdraft. This does not preclude the possibility of the pilot's entering a cloud and being swamped, so to speak, even though rain has not been observed from surface positions. Rain will be found in almost every case of penetration below the freezing level. There have been instances in which no rain was reported; the storm probably had not developed into the mature stage.

Statistics show that, although heavy rain was generally reported at all levels of a mature storm, certain specific flight altitudes seem continually to present the greatest frequency of heavy rain. In all observations the greatest incidence of heavy rain occurred in the middle and lower levels of the storms. The 10,000- to 11,000-foot level showed the greatest fre-

Turbulence Intensity	Precipitation Intensity					
	Rain			Snow		
	Light	Moderate	Heavy	Light	Moderate	Heavy
Light	310	111	39	335	75	14
Moderate	87	104	101	87	101	37
Heavy	18	19	53	19	23	54
None	48	15	13	39	5	2

Figure 42—Precipitation-Turbulence Correlation.

quency and the 5,000- to 6,000-foot level showed the next greatest frequency of heavy rainfall. Altitudes above the freezing level showed a sharp decline in the frequency of rain of any intensity.

There is a certain definite correlation between turbulence and precipitation. Previously it was believed that precipitation would have a dampening effect on turbulence. This has been found to be nearly 100 per cent in error. From the preceding table it is clearly evident that the intensity of associated turbulence, in most cases, varies directly with the intensity of precipitation. (Fig. 42).

Hail

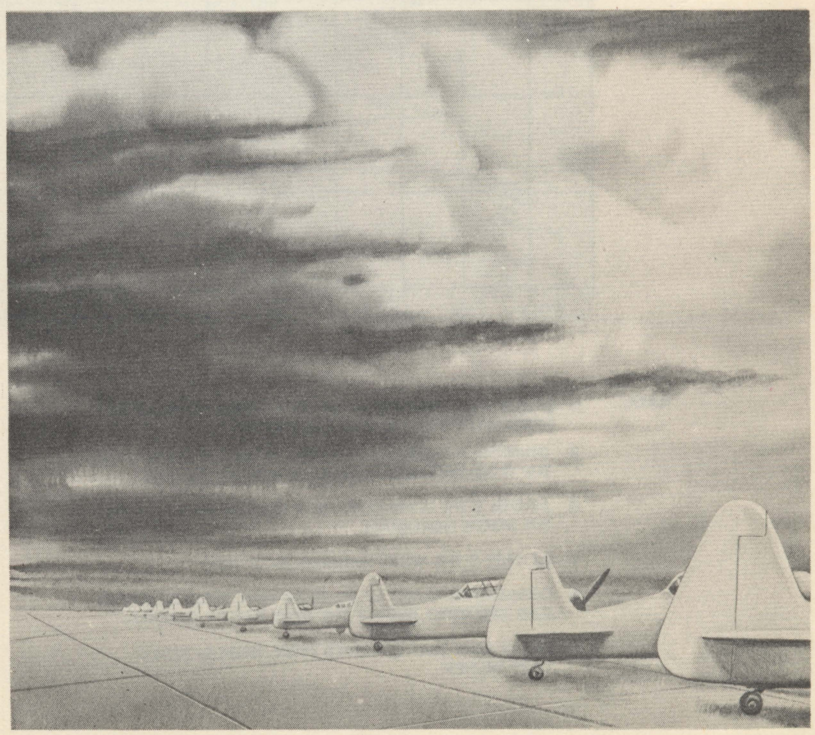
During the operations of the project, hail was encountered at a maximum of 10 per cent of the traverses at any given altitude. Very seldom was it found at more than one or two levels within the same storm. When it was observed, its duration of occurrence was very short. The total occurrence was found to be at a maximum at the middle levels for all intensities of hail. However, the area from which the data are taken is far removed from the region of greatest surface hail, the Great Plains States.

Lightning

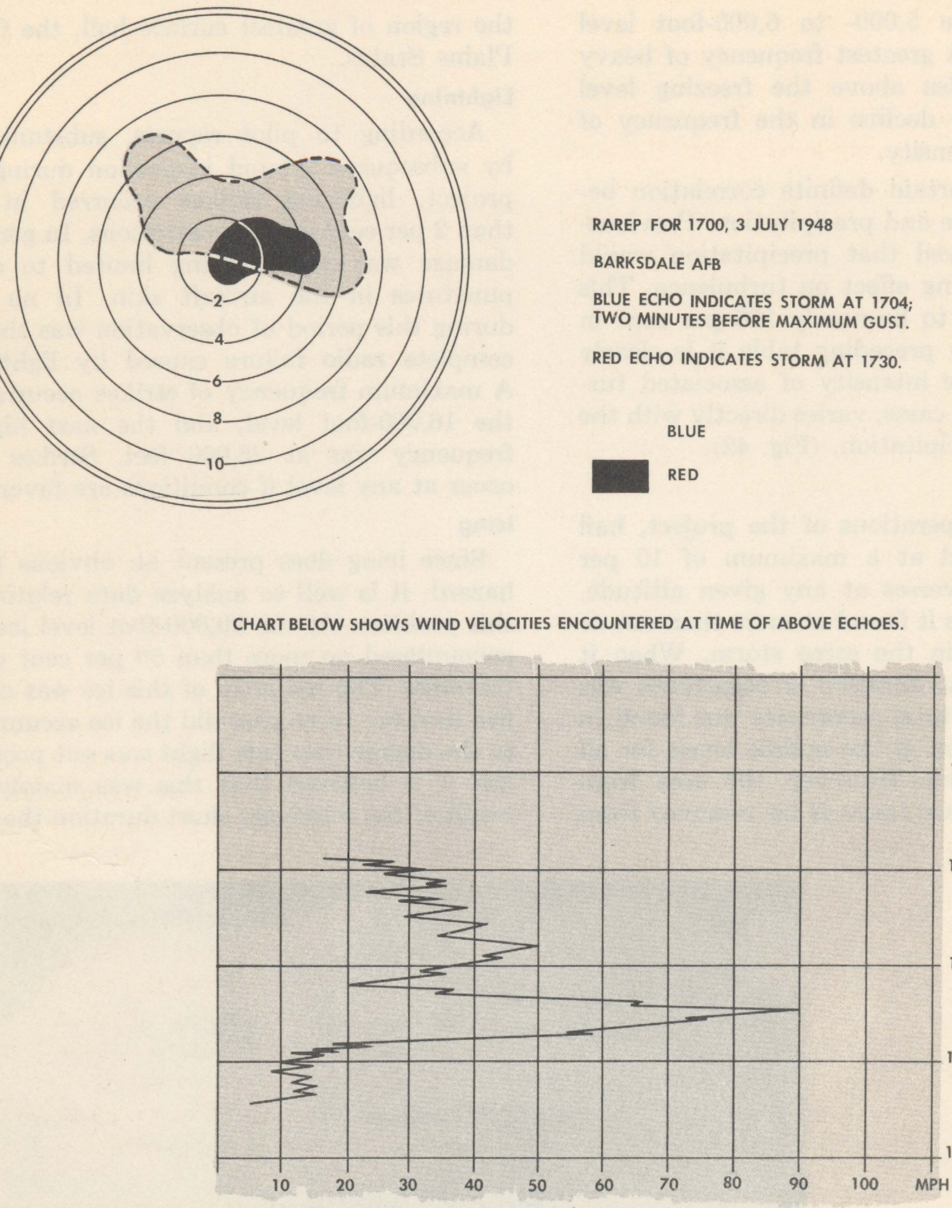
According to pilot reports, substantiated by subsequent ground inspection during the project, lightning strikes occurred in less than 2 per cent of all penetrations. In general, damage was minor, being limited to small punctures in the aircraft skin. In no case during this period of observation was there a complete radio failure caused by lightning. A maximum frequency of strikes occurred at the 16,000-foot level, and the next highest frequency was at 26,000 feet. Strikes may occur at any level if conditions are favorable.

Icing

Since icing does present an obvious flight hazard, it is well to analyze data relating to this problem. At the 20,000-foot level ice was encountered on more than 50 per cent of all traverses. The majority of this ice was classified as *rime*. In no case did the ice accumulate to the degree that safe flight was not possible, but it is believed that this was mainly the result of the relatively short duration that air-



Typical storm cloud appearance just prior to first gust and high winds.



DATA:

1. STORM WAS FIRST PICKED UP AS A SMALL ECHO ABOUT SEVEN MILES OUT, MOVING NORTHWEST.
2. THUNDER WAS HEARD AT 1700 C, FROM THE CLOUD AND THE WIND WAS RECORDED AT 10 MPH AT THE TIME.
3. AT 1706 C THE WIND REACHED A PEAK OF 90 MPH. FROM THE NORTH NORTHEAST.
4. AT 1708 C THE WIND SUBSIDED TO 20 MPH.
5. OCCASIONAL GUSTS UP TO 50 MI. MPH. WERE OBSERVED AND RECORDED DURING THE NEXT FIFTEEN MINUTES.
6. HEAVY RAIN WAS OBSERVED FROM 1703C to 1710 C (0.39 INCHES)

Figure 43—Thunderstorm: Barksdale Field, Louisiana, July 1948.

craft were subject to icing conditions in these traverses. Since ice necessarily requires freezing temperatures, it is reasonable to assume that the icing level will lower with the freezing level. Since the freezing level is also the zone of greatest frequency of heavy turbulence, and generally heavy rainfall, this particular altitude appears to be the most hazardous.

Snow

The maximum frequency of moderate and heavy snow occurred at the 20,000- and 21,000-foot levels. Snow, mixed in many cases with super-cooled rain, was encountered at all altitudes above the freezing level. This was apparently of considerable concern to the pilots, for it presented a unique icing problem; wet snow packed on the leading edge of the wing and resulted in the formation of rime ice.

SURFACE PHENOMENA

First Gust

A significant hazard associated with thunderstorm activity is the rapid change in wind direction and speed immediately prior to storm passage. The strong winds at the surface accompanying thunderstorm passage are the result of the horizontal spreading-out of the downdraft currents from within the storm as they approach the surface of the earth. The total wind speed is a result of the downdraft divergence plus the forward velocity of the storm cell. Thus, the speeds at the leading edge, as the storm approaches the field, are far greater than those at the trailing edge. This initial wind surge as observed at the surface is known as a "first gust." The speed of this first gust is normally the highest recorded during storm passage and may vary as much as 180° from the previously prevailing surface wind. First-gust speeds increase to an average of about 18 mph over prevailing velocities, although gusts of over 90 mph have been recorded. The average change of wind direction associated with the first gust is 39°. Wind shifts greater than 90° occur at the surface in only slightly over 10 per cent of cases.

A first gust of 90 mph was recorded during a storm passage at Barksdale Field, Louisiana, on 3 July 1948 at 1700C. This speed was maintained for nearly a full minute and was followed by gusts of as high as 50 mph. The total period of high gustiness lasted approximately 15 minutes.

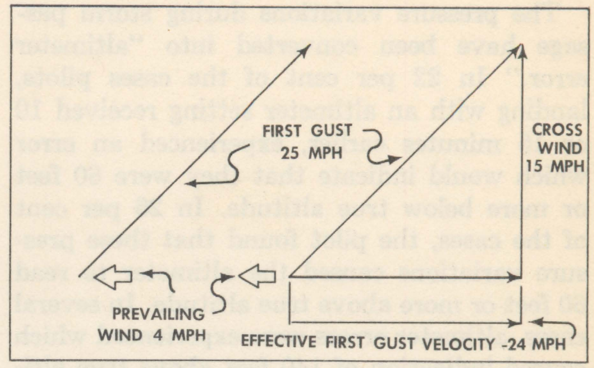


Figure 44—Outflow pattern of the surface wind under a radar echo.

Effective First-Gust Speed

The measurement termed "effective first-gust speed" is of considerable importance to the pilot. It is the component of first-gust velocity relative to the longitudinal axis of an airplane heading into the previous prevailing wind. In 38 per cent of the cases observed, the positive effective-first-gust speed exceeded 10 mph, whereas in only 1 per cent of the measurements did the negative values exceed 10 mph. This is important since a negative speed would overtake the airplane, resulting in a loss of air speed during take-off or landing. This occurs infrequently; however, it must be considered.

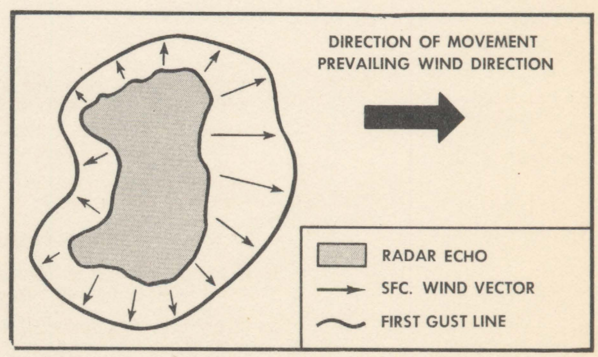


Figure 45—Method of determining effective first gust (in this case, negative).

ALTIMETER ERRORS

The pressure variations during storm passage have been converted into "altimeter error." In 22 per cent of the cases pilots, landing with an altimeter setting received 10 or 15 minutes earlier, experienced an error which would indicate that they were 60 feet or more below true altitude. In 26 per cent of the cases, the pilot found that these pressure variations caused the altimeter to read 60 feet or more above true altitude. In several cases, altimeter errors were experienced which caused indication of 140 feet above true altitude. The largest surface pressure increases occur during periods of heavy rain. The pilot must realize that altimeter settings given during such time may soon be in error.

CONCLUSION

Heretofore many theories relative to thunderstorm structure and associated weather have been advanced, but many of these conflicted, and little or no conclusive evidence was presented.

The latest achievements in quantitative thunderstorm analysis constitute a significant stride toward obtaining concrete data regarding the actual weather peculiarities and hazards associated with thunderstorms. As further work of this type progresses, the thunderstorm hazard will be diminished until it may be treated with the same confidence and lack of apprehension as other common weather situations encountered in flight.

CHAPTER THIRTY-THREE

Fog

Unlike other weather hazards a pilot is likely to encounter, fog presents little or no hazard during en route flight. Fog is mainly a hazard likely to be encountered at the destination when attempting to effect a landing. The pilot should be familiar with the various types of fog and the causes for their formation and dissipation. Fog is defined as minute droplets of water suspended in the atmosphere. The droplets have no visible downward motion. Fog is different from clouds in that the base of fog is at the surface while the base of clouds is above the surface. Fog is easily distinguished from haze by its dampness and grey color. If the pilot plans his flight properly, he should suspect the possibility of fog at his destination and select a suitable alternate.

FOG FORMATION

The three factors that favor the formation of fog are: high relative humidity, light wind, and condensation nuclei. Particularly important is the necessity of a high relative humidity. A high relative humidity may be noted on the Hourly Teletype Reports by observing the spread (difference in degrees of temperature) between temperature and dew point. Fog rarely occurs when the spread is more than 4° and occurs more frequently when the spread is from 2° F to 0° F. A certain amount of wind is necessary for fog formation. A precise amount of mixing action is required, caused by the wind; however, winds of more than 10 mph exceed the critical speed and have a negative effect. Lastly, there must be, suspended in the air, condensation nuclei. These nuclei provide a base on which moisture condenses. Smoke and salt particles are the most common forms of nuclei found in the atmosphere.

FOG DISSIPATION

Turbulence caused by strong winds causes fog to dissipate by entraining warm air from the inversion level and transporting it to the surface, thus widening the temperature-dew point spread. The heating of the earth's surface by the sun increases the temperature of the air in the lower layers which results in a widening of the temperature-dew point spread and the fog evaporates.

FOG TYPES AND CHARACTERISTICS

One common type of fog encountered by the pilot is ground fog which is formed solely by radiational cooling. After sunset, the

earth radiates heat gained during daylight hours, and by early morning the temperature at the surface may lower as much as 20° which materially affects the temperature-dew point spread. If the radiational cooling is great enough and other factors are present, ground fog results. This fog is most commonly found when the following conditions prevail:

1. Clear skies at night (maximum radiation).
2. Low, steady wind.
3. Constant or increasing relative humidities in the lower layers.
4. A high pressure cell.

A second type of fog is advection fog. Advection fog is very common along coastal regions, and is formed by the movement of moist air over a colder surface.

One example of this fog is sea fog. Sea fog is formed out over the water. Cold ocean currents, such as are present off the coast of San Francisco, serve to cool and condense warm, moist air which comes from sea currents flowing farther west. This fog is carried inland by the wind and is usually very intense.

Advection fog is very common in the gulf states area during the winter when warm, moist air moves inland over cool land surfaces.

The third type of fog, which is called upslope fog, is formed by the transportation of air up a rising land surface. As the air rises, it cools by expansion as a result of the decrease in barometric pressure resulting from height. This type of fog is formed by adiabatic cooling which is entirely different from those previously mentioned. The most common fog of this type is formed by the westward flow of air from the Missouri Valley which produces fog on the eastern slope of the Rockies. This type of fog has been observed to persist with winds as high as 35 mph.

All other type fogs are classified under the general term evaporation fogs. Included within this group are the frontal fogs which are fairly common in the winter months and are associated most commonly with slow moving systems. They are always found in the cold air mass under warm, moist air. Precipitation from the warm air falls through the colder air and evaporation takes place. Prefrontal fog accompanies a warm front, and postfrontal fog is associated with a cold front.

Rain-area fog may occur at any time warmer liquid precipitation falls through colder stable air.

Steam fogs occur where colder, stable air overflows a water surface several degrees warmer than itself. In order for the "steam" to form a fog, there must be a strong inversion, very light winds and clear nights. They are common around lakes and rivers in the fall months of the year.

Fog is mainly a hazard which the pilot encounters in the approach or landing. Having checked the weather information and discussed the weather with the forecaster, the pilot should be reasonably prepared should fog be present at his destination. It is particularly important for the pilot to use a good alternate destination rather than attempt a landing or circle in hopes that the condition will clear.

CHAPTER THIRTY-FOUR

Icing

There are three major hazards with which the pilot has to contend: fog, turbulence, and icing. Instrument flying techniques and procedures have diminished the dangers of fog and turbulence, but icing is a more complex problem. Despite the voluminous amount of written material on the subject, not many facts are definitely known. Confusion results in conflicting reports from the pilots in flight. The following information is intended to acquaint the pilot with the latest ideas and observations on the subject.

RESULTS OF ICE ACCRETION ON AIRCRAFT STRUCTURES

The presence of ice on the airfoil disrupts the smooth flow of air and thus decreases lift and increases drag. Ice on the propeller causes a loss of efficiency which results in a loss of thrust. The addition of ice to the various structural parts of the aircraft results in vibration, causing added stress on these parts. This is especially true in the case of the propeller, which is very delicately balanced. Even a very small amount of ice, if not distributed smoothly, can cause great stress on the propeller and engine mounts. The danger of added weight is not too great under ordinary circumstances if too much of the lift and thrust are not simultaneously lost. It does become an important factor, however, in critically loaded aircraft.

FACTORS NECESSARY FOR ICE FORMATION

Freezing temperatures are necessary for the formation of ice. Observations have shown that ice may form on a static object when the free-air temperature is as high as +2° C. as a result of evaporational and adiabatic cooling. When an aircraft is in flight, the heating from skin friction and the impact of water droplets cause the temperature of the skin to rise. For all practical purposes the heating and cooling effects cancel each other out; thus, structural ice can be considered to be possible only at 0° C. or below.

The frequency of ice formation decreases gradually with lowering temperature and the most severe icing is encountered between 0° and −8°; however, dangerous icing conditions may often be encountered below −8° C.

The free-air thermometer is not too accurate, and, in some aircraft, it has been mounted improperly. The pilot should know this error (if it exists) and mentally apply the correction.

The second factor necessary for structural ice formation is the presence of liquid moisture visible to the naked eye.

FORMS OF VISIBLE LIQUID MOISTURE

Clouds are the most common form of visible liquid moisture; however, not all clouds at temperatures below freezing give rise to ice formation. The pilot does not have any way of knowing which clouds will present an icing situation, but he must be aware that the possibility exists if the temperature is below 0° C.

Freezing rain may be encountered in clear air below a cloud deck. When warm moist air is forced to rise over a colder air mass, a frontal inversion will exist. Below this inversion icing dangers are frequently encountered. In being forced aloft, the air may be sufficiently cooled to produce saturation and precipitation. The raindrops falling into the cold air may freeze upon contact with the aircraft if the temperature is at freezing or below. Freezing rain is without doubt the most dangerous form of ice because it can build to stupendous proportions in a matter of minutes and is extremely hard to break loose.

The typical situation necessary for freezing rain is illustrated in Figure 46.

FACTORS INFLUENCING THE RATE OF DEPOSIT OF ICE ON AIRCRAFT

The amount of liquid water available has a definite value in determining the rate of deposit, the more liquid available the more pronounced and rapid the deposit.

SIZE OF THE DROPLETS OF WATER

When a wing moves through the air, the air is deflected at the leading edge. If water droplets are present in the air, they tend to move with the air stream, the smaller the drops, the greater their tendency to follow the air stream; and the larger the drops, the more they resist this deflecting influence. Therefore, the large drops (small deflection) are collected more easily than the small drops (large deflection).

Air speed is a factor to be considered because as air speed is increased, the rate of deposit is increased.

ICE FORMS THAT MAY BE ENCOUNTERED

Hail

This form of ice develops in highly turbulent thunderstorms. Water drops, which are carried upward by vertical currents, freeze into ice pellets, start falling, accumulate a ring of water, and are carried upward again;

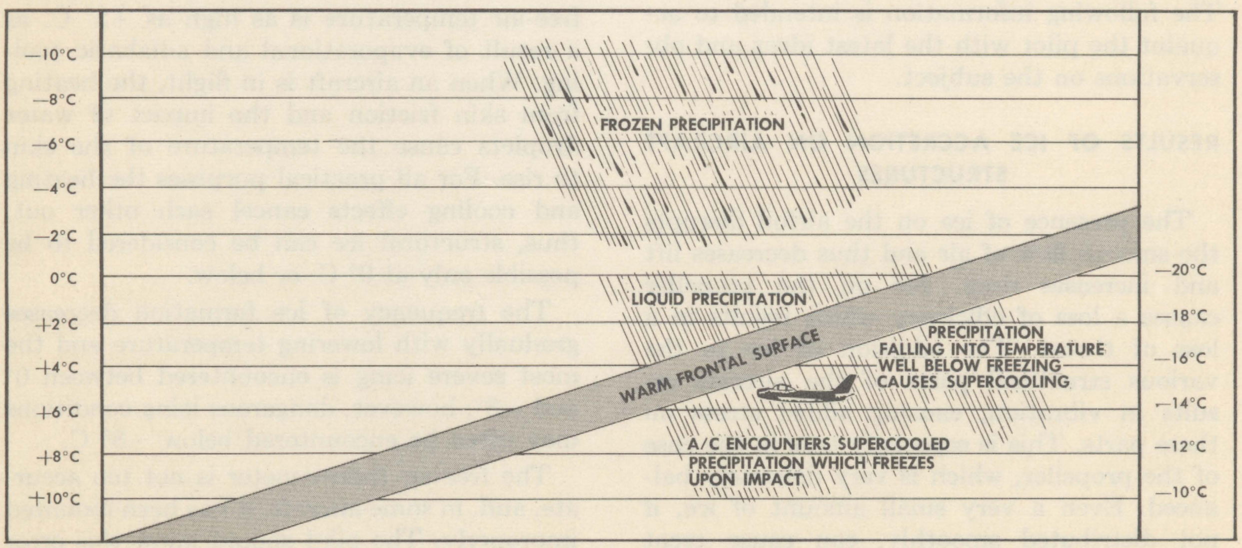


Figure 46—Typical freezing rain situation.

the newly added water freezes. A repetition of this process increases the size of the hailstone. Hail is a warm weather phenomenon and can be produced only by strong vertical currents. It does not lead to the formation of structural ice, but in some cases, it causes physical damage to the aircraft.

Sleet

When raindrops fall through the air that is below freezing, they may freeze to form sleet. This form of ice is a cold weather phenomenon. It does not bring about the formation of structural ice except when mixed with supercooled water.

Snow

When condensation takes place at temperatures below freezing, water vapor changes directly into minute ice crystals. A number of these crystals unite to form a single snowflake. Dry snow does not lead to the formation of structural ice, but wet snow does.

Carburetor Ice

Carburetor ice really constitutes a problem that is different from structural ice; it can be formed when structural ice is impossible to form. If the humidity is high, carburetor ice may occur with temperatures as high as 21° C. because the cooling to freezing temperatures is accomplished by the evaporation of the gasoline and the decrease of pressure in the Venturi tube.

Types of Structural Ice

There are several types of ice which will adhere to the surface of aircraft. It is important to know the various types of ice since the characteristics vary depending upon the type.

CLEAR ICE (glaze). This type is considered to be the most serious of the various forms of structural ice. It is most often encountered in regions of large supercooled (liquid at below freezing temperatures) water droplets. This condition most often presents itself in regions of unstable (cumuliform) weather conditions, in and below cumuliform clouds. Clear ice is dangerous due to the great amount of freezing water available and the resulting high rate of accretion. Moreover, the fact that the water droplets do not freeze immediately upon impact allows air foil deformation, in some cases, in clear icing conditions. Clear ice is very tenacious.

RIME ICE. This type of ice is generally encountered in stable (stratus) weather conditions. The very fine moisture particles of a stratus cloud freeze immediately upon impact with the aircraft surface. Rime ice builds up slowly by comparison to clear ice. The greatest resultant danger is the added drag caused by the very rough ice surface created. Rime ice is relatively easy to break loose by conventional methods.

FROST. This hazard is very often underestimated. Frost may form on the ground or in the air. On the ground, frost is likely to form during the night when surface temperatures are freezing. Frost forms in clear air by sublimation (change of state directly from gas or vapor to solid ice) when the moist air comes into contact with a very cold surface. Frost may form in flight when descending into warmer (but still freezing), more moist air, or when flying from a very cold air mass to a warmer air mass. Frost causes added drag and offers a very real hazard at lower, more critical air speeds. However, bearing this latter fact in mind, the most annoying frost hazard is the restriction to visibility caused by frost on windshield surfaces.

COMBINATION. It should be realized that the various icing forms and attendant hazards may often occur in any and all combinations if the weather situation allows.

Anti-Icing and De-Icing Aids

An anti-icer is an item of equipment that prevents the formation of ice, and a de-icer is an item of equipment that eliminates ice after it has already formed.

Anti-icing and de-icing equipment can be divided into three general classes:

1. Mechanical (de-icing boots which are used on wings, tail assembly and radio mast).
2. Chemical (anti-icing fluid and paste)—Anti-icing paste is used on propellers and anti-icing fluid is used on the propeller, windshield, and carburetor.

3. Thermal (electrical heat and exhaust heat)—Electrical heat is used on the pitot tube, and exhaust heat is used on the wings and tail assembly, windshield, and carburetor.

Anti-icers should be used prior to, or immediately upon, entering an icing zone and operated continuously until the aircraft is out of the icing zone.

De-icing boots should be used intermittently and only after an appreciable thickness of ice has accumulated upon the boot. De-icing boots are most useful in eliminating rime ice but are not so reliable in removing clear ice. They should not be used during take-off or landing.

The "hot wing" or exhaust heat may be considered either an anti-icer or de-icer, depending upon the time at which the unit is put into operation.

ADDITIONAL FACILITIES

At the weather station there are charts, facilities, and a qualified forecaster to aid the pilot in flight planning. These facilities are listed and explained below:

Weather Maps

These maps show the pilot the positions of fronts and thus the regions of possible ice formation. This is important, too, because the warm front presents a dangerous situation. It may extend over a great area, vertically and horizonally, and severe icing conditions may be present at any point in it. In the smooth clouds the ice is generally rime, but in the turbulent and freezing rain areas, the ice is clear.

In cold fronts, prefrontal squall lines, and air-mass thunderstorms, usually clear ice is formed as a result of the turbulence and the large water droplets.

Occluded fronts present less of an icing hazard because, in these situations, precipitation has been occurring for quite some time. Consequently, there is less liquid water available for ice formation and the rate of deposit is less. The cloud cover in an occlusion, however, is generally extensive, and the time spent in these clouds will be great.

The circulation as shown by the isobars also gives information regarding icing dangers. The isobars may indicate:

a. Upslope motion—When air is carried upslope, condensation occurs, and if the temperature is below freezing, icing occurs. The pilot should check to see if the air is flowing in this manner.

b. Air flowing from cold land over warm water. This occurs in the vicinity of the Great Lakes and over the Atlantic along the northeastern and middle Atlantic states. The cold air is heated from below, absorbs moisture from the water, turbulent clouds form, and clear ice forms.

Air Weather Service and Weather Bureau Written Forecasts

Both types of forecasts give information on the height of the freezing level and regions in which the pilot can expect ice formation. The type and intensity of ice to be expected are usually omitted because of the difficulty in forecasting these items. Since it is oftentimes possible to fly in clouds at temperatures below freezing and not pick up any ice, the forecasts may seem to be in error. These forecasts, then, simply indicate regions where conditions are favorable for ice formation. The pilot should be prepared to encounter ice and consider himself fortunate if he does not encounter it.

Teletype Weather Reports

The pilot should note where the surface temperatures are below freezing and where clouds are reported. The occurence of hail, sleet, freezing rain, and snow will also be reported and should be noted.

Pilots' reports of icing will often be included in the teletype weather reports and will provide the pilot on the ground with much useful information before take-off.

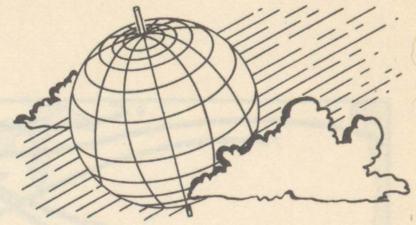
Adiabatic Chart

This chart enables the pilot to determine the height of the freezing level and the presence of clouds. It also shows the presence of an inversion. Oftentimes freezing temperatures exist on the surface while temperatures aloft

will be above freezing. Many times a pilot is able to fly at the altitude of the inversion, picking up ice only during climb and descent. Caution should be exercised in making a selection of an altitude, and the help of the forecaster should be sought. Beneath an inversion, icing conditions may be present in freezing rain or lower clouds. The pilot should be prepared for ice while descending. The reduction of visibility during landing because of ice on the windshield may require the opening of a side window or, if necessary, breaking part of the windshield.

Despite all planning to avoid an icing situation, there are times when the pilot will run into such a situation either through choice or chance. If the aircraft is equipped with thermal de-icers, no problem exists; if it is equipped with wing-boot de-icers, rime ice can usually be handled without difficulty, but clear ice is much more difficult to overcome. If the ice eliminating equipment is inoperative or if the pilot does not have such equipment, a reduction of air speed will decrease the rate of ice formation; however, the air speed should not be lowered to such an extent that ice forms on the under-surface of the wings because of a high angle of attack.

CHAPTER THIRTY-FIVE



World Weather

WORLD WEATHER (UNITED STATES)

The general air circulation in the United States is south westerly (sw). All weather systems move with the sw circulation. This is only the average circulation and it must be noted that although the weather systems (cyclones or low pressure areas) move from sw to northeast the fronts associated with the low-pressure area may move south if they are cold fronts and north if they are warm fronts.

Since the average circulation in the mid-latitudes is west to east, most storm areas or cyclones move with the general circulation. Because of this it has been possible to observe and plot average storm tracks. The greater majority of cyclones (lows) follow one of these paths as they cross the continental United States from west to east Fig. 47.

This discussion is limited to that section of North America which lies in the temperate zone which is under the influence of the polar front and the inter-tropical zone of convergence. A great part of the weather in the United States, however, is the direct result of the influence of the polar front. The immediate effect of these storms on the weather conditions in any particular area in the United States and Canada may be changed by terrain and circulation effect both of which distinctly influence the local weather picture. In order to study local weather, the United States has been divided into 7 main weather zones as are shown in Figure 48. These zones are:

1. N. W. Pacific Coast Area.
2. S. W. Pacific Coast Area.
3. West Central Inter-Mountain Area.
4. S. W. Desert and Mountain Area.
5. Central Plains Area.
6. S. E. and Gulf States Area.
7. Northeast Altantic Coast Area.

Northwest Pacific Coast Area

This area has more rainfall than any of the other areas. The weather in this sector is caused by the combination of frontal phenomena, mainly in the form of occlusions which move in from the area of the Aleutians low into the coast of the N.W. Pacific, and orographic lifting of moist stable maritime air. The predominant cloud forms are stratus and fog which are common in all seasons. Rainfall is most frequent in the winter and least frequent in the summer.

Southwest Pacific Coast Area

A Mediterranean-type climate exists in most of the S.W. Pacific coast area which is distinctive from any other North American

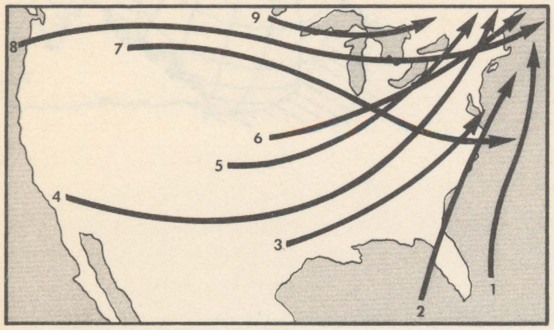


Figure 47—Average U. S. storm tracks.

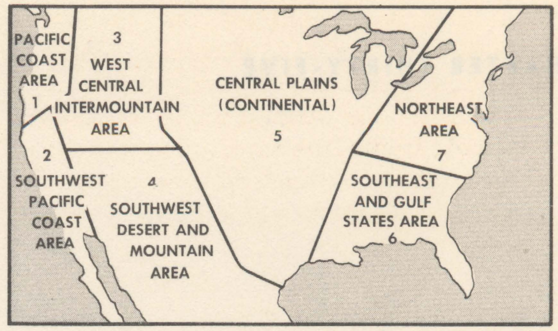


Figure 48—North American temperate weather zones.

climate. It is called Mediterranean because the same type of weather is most extensive in the area around the shores of the Mediterranean Sea. In the northern hemisphere this type occurs only in the Mediterranean area and Southern California, and in the southern hemisphere, it occurs in small areas of Chile, South Africa and Southern Australia.

The climate in this area is characterized by warm to hot summers tempered by sea breezes and mild winters during which, temperatures seldom fall below freezing. There is found little or no rainfall in the summer and only light to moderate rain in the winter.

Cold fronts rarely if ever penetrate this region, and most weather is caused mainly by circulation of moist Pacific air from the west which is forced orographically up the slope of the coastal range. In the summertime this air is generally stable, and stratus and fog result from this lifting. In the winter unstable air rising over these ranges causes showers and snow storms in the mountains. Hazards presented to flying are the low ceilings, showers, and poor visibility in the fog and rain showers.

West Central Inter-Mountain Area

The climate here is described in general as cold and dry in winter and warm and dry in summer. Most of the region is semi-arid. The western mountain range acting as a climate barrier has an extreme drying effect on air in the westerly circulation pattern.

The maximum rainfall is in the spring-time and is due mainly to the predominance of cyclonic storm track passage. In midwinter a cold high is generally centered in this region which precludes the possibility of cyclonic storm passage to any great extent. Annual precipitation is light. Chief flying hazards in this region are found in the area of west-to-east-moving frontal zones. The weather is similar to typical frontal weather for the synoptic situation involved.

Southwest Desert and Mountain Area

This area is almost completely surrounded by high mountains and is all very arid or actually desert. Modest vegetation exists only in mountain and irrigated areas. The most northern parts of this section have cold winters and all parts have extremely hot summers. The chief flying hazard is the predominance of summer and spring thunderstorms caused mainly by mT air penetrating into this area with the expansion of the Bermuda high in summer and being forced aloft at the mountains. For this reason nearly all significant peaks and ranges have thundershowers forming over them in spring and summer. They are generally scattered but always severe.

Central Plains Area

The western section of this area is rather dry and the moisture increases to the east. The main weather hazard is presented with the wintertime outfluxes of the polar front and associated wave phenomena; and also the formation of convective-type air mass thunderstorms which are prevalent in the summertime. Frontal passages, both cold and warm, with typical associated weather, are common throughout this area. Thunderstorms usually form convectively and are very severe.

Southeast and Gulf States Area

This area is affected by the circulation phenomenon known as Gulf Stratus. Weather forecasting for this area is exceptionally difficult owing to the stagnation of southward moving cold fronts, the rapidly moving squall lines, circulation thunderstorms, and the Gulf Stratus situation which often occurs in various combinations.

Frontal passages occur only in the late fall, winter, and early spring. The weather depends upon the type of front. It is not uncommon for cold fronts to stagnate in this area.

In the wintertime, when the circulation near the surface is southerly, the warm moist gulf air is cooled from below until the point of saturation is reached. In this case fog and stratus are very common and may cover the area for many days. Southerly circulation in the summer, however, causes warm moist air to be heated from below and form convective thunderstorms. The maritime tropical air causes the storms to be generally quite severe.

Northeast Atlantic Coast Area

This is an area of storm track convergence and cyclonic storm activity and accompanying weather is frequent in the wintertime. These storms are intensified by heating and addition of moisture over the Great Lakes. The increased moisture content is directly accountable for the great amounts of snowfall peculiar to this area in the wintertime. Generally good weather prevails in the summertime as a result of the dominating influence of the Bermuda high.

WORLD WEATHER (TROPICAL)

Until recently, most meteorologists have neglected tropical weather analysis partly because of a lack of reliable data and partly because it has been the practice to consider hurricanes as the sole weather phenomena in this area which is supposedly free from other synoptic weather problems. In the last few years this has been found to be incorrect.

There is a lack of well-defined air masses in this region. Consequently, frontal phenomena are absent. Nevertheless, there are certain specific tropical phenomena which are readily recognizable in any synoptic analysis and may be studied as such.

A very weak pressure gradient and lack of distinction of air masses make the vertical cross section and atmospheric soundings of outstanding importance in analysis of tropical weather. It was by use of these soundings that an extreme difference between the moisture content of the lower level air and that of the upper, superior air was first observed.

THE TRADE INVERSION

The air in that region between 20° north and 20° south latitude, generally referred to as the tropics, flows over a surface almost completely covered by water. Convective mixing on the lower levels causes a definite layer of moist air up to about 10,000 feet. This is called the moist layer. The actual height of this moist layer varies considerably, depending upon the particular local synoptic situation. Above this moist layer lies extremely dry, superior air. Between the moist layer and the superior air is generally found a well defined temperature inversion. This inversion is a result of the rapid change of moisture content between the two layers. In the lower layer of air the circulation is easterly. These easterly winds are called "trade winds." In the superior air aloft the wind is westerly. The inversion between the two layers is known as the "trade inversion." It is significant to note that the actual height of the trade inversion, or top of the moist layer, directly indicates whether the area is one of convergence or divergence. If there is convergence in the area, the moist layer will be considerably higher than average. If the area is one of diverging or sinking currents, the trade inversion will be lower than average. The height of the trade inversion is by far the best index for forecasting tropical weather.

TROPICAL SYNOPTIC PHENOMENA

Tropical weather phenomena falls into two main categories: those peculiar entirely to tropical zones which move with the easterly circulation in the tropical air; and those that merely penetrate the tropics as outgrowths

of systems originating in the temperate regions and move the westerly winds in the area of their origin. The following are some of the main tropical weather phenomena.

Easterly Waves

This condition of weather originates near the northwest coast of Africa. The moist layer of air, west of the wave, is low (about 8,000 feet) but to the east the height of the moist layer of air may be as high as 30,000 feet. The line of the wave is indicated by a wind shift from southeast on the east side to northeast on the west side. West of the wave, clear skies prevail with possibly a few scattered cumulus. To the east, thunderstorms, low ceilings, rain, and generally rough weather predominate. The waves travel with the easterly circulation around the bottom of the semi-permanent subtropical highs. (Fig. 49.)

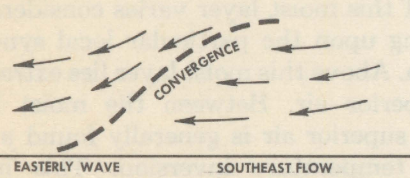


Figure 49—Typical southern hemisphere north-east flow at regions other than near heat equator.

Polar Troughs

Polar troughs appear in the tropics when cP outbreaks from the north push quite far south. The trough (region of cyclonic circulation) extends aloft into the tropical regions and appears there as a trough in the upper air. The effect of this phenomenon is similar to an easterly wave in that there is a cyclonic wind shift across the trough, clear weather to the west and a storm area to the east, but the system moves from west to east with the circulation in the temperate zone. (Fig. 50.)

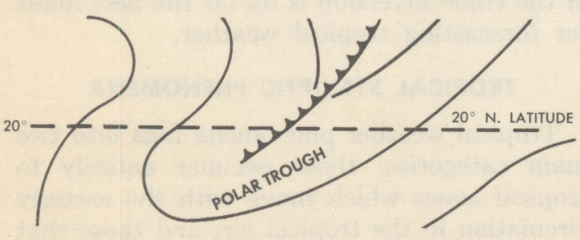


Figure 50—The polar trough in the tropics.

Shear Line

The shear line is found in the tropics when the leading edge of a cP high is displacing the semi-permanent tropical high. Mixing in these lower latitudes causes the density discontinuity across the front to disappear leaving only a wind shift. Convergence and cumuliform activity are found along this wind shift line. Convergence causes the height of the trade inversion to reach 25,000 feet or more.

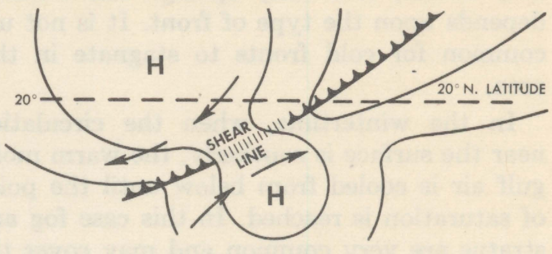


Figure 51—Shear line.

Induced Trough

The induced trough is the direct result of the synoptic set-up involved in the case of the shear line. It is caused by the apparent cyclonic circulation between the two high cells. Again convergence and cloud forms are present. (Figure 52.)

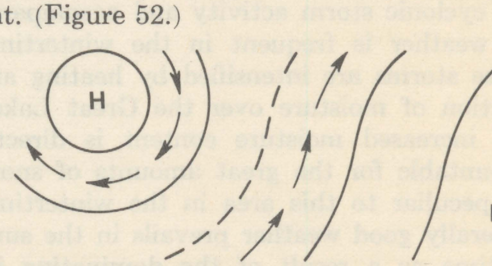


Figure 52—Induced trough.

Intertropical Convergence Zone (Intertropical Front)

The subtropical high-pressure areas of both hemispheres are separated in the region of the "heat equator" by a trough of low pressure in which the hot tropical air is converging and rising aloft. This is the intertropical convergence zone, abbreviated "ITC". The ITC is not a true front because there is no density discontinuity involved, but the lifting of the warm moist air causes a line of high cumulus clouds and shower and thunderstorm activity in the region of the heat equator. The ITC

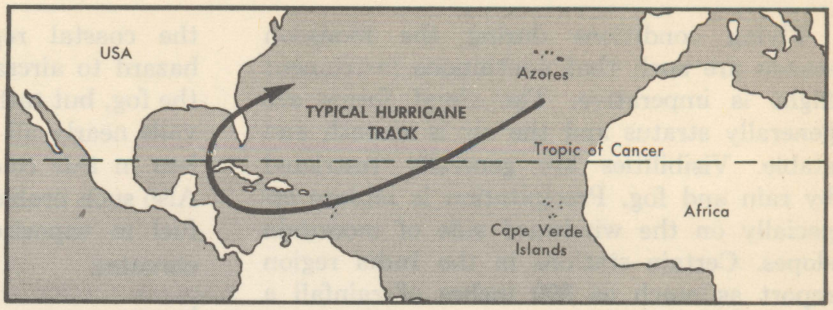


Figure 53—Average Atlantic hurricane path.

moves northward in our summer and southward in our winter.

Tropical Depressions

The most mature and most intense of the tropical depressions are known the world over by many names. These are the infamous hurricanes, known also as "typhoons" in the region of the South China Sea, "wooly woolies" in the Australia region and as "tropical cyclones" in the South Pacific. The great majority of tropical depressions never develop into the hurricane stage. These tropical lows generally start out as perturbations on the intertropical "front." They are classified according to their stage of development as follows:

a. Tropical disturbance.

b. Tropical depression.

c. Tropical storm (Wind force — Beaufort #6 or over).

d. Hurricane (Wind force—Beaufort #12 or over).

These low-pressure regions originate in the vicinity of the Azores and travel with the general easterly flow while in the tropics. As momentum is built up they veer to the north in the northern hemisphere and encounter the southwesterly extra tropical flow. (Fig. 53.)

Monsoon

No discussion of tropical weather phenomena is complete without including the mechanics of the monsoon circulation. The monsoon is more than a simple, temporary phenomenon, it is a season of the year, throughout which typical weather persists.

The variation in specific heat between land and water causes relatively more heating over land in the summer and over water surfaces in the winter. For this reason there is a strong tendency in the average world pressure pattern, for highs to form over land in the winter and over water in the summer; likewise, lows form mostly over land in the summer and over water in the winter. This, in effect, is the basis for the phenomenon of monsoon circulation. In the India, Burma, China region, the land and water areas are so located in relation to the seasonal circulation that during the summer season the southerly circulation is intensified, and, in the winter season the northerly circulation becomes predominant. The southerly circulation in summer brings in the warm moist air to the continent. When this air is lifted over the land, stratus clouds, precipitation, and poor visibilities result. The winter situation brings in the very dry air downslope from the north. (Fig. 54.)

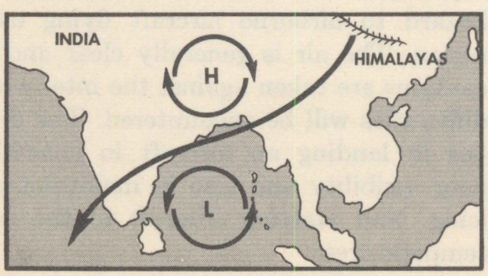


Figure 54a—Winter monsoon.

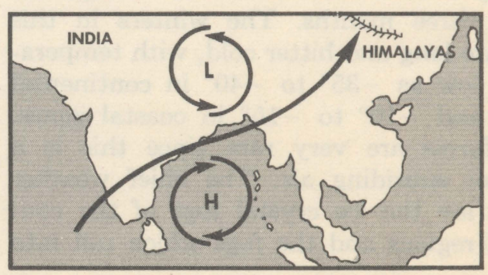


Figure 54b—Summer monsoon.

Flying conditions during the monsoon season are such that continuous instrument flight is imperative. The cloud forms are generally stratus and the air is smooth and stable. Visibilities are generally restricted by rain and fog. Precipitation is intense especially on the windward side of mountain slopes. Certain stations in the India region report as much as 300 inches of rainfall a year. About 75 per cent of this falls between June and October.

WORLD WEATHER (POLAR)

In the region of the north and south poles, the sun is out of sight for about 6 months of the year and above the horizon for an equal period. Even during that part of the year when the sun is above the horizon, it never rises very high. This, and the extreme back radiation of the sun's rays as they are reflected from the permanent ice fields, makes this polar region one of intense cold nearly all year.

The area on the earth's surface lying north of 60° latitude (in the northern hemisphere) may be defined as the polar region. This is that section of the troposphere lying north of the polar front. It is a region of generally high atmospheric pressure and subsiding cold air; the source region of maritime and continental polar air masses. For specific weather analysis, this polar zone is subdivided into two main categories: tundra and icecap.

Tundra

The tundra is that section of the polar region which has more than a 32° but less than a 50° average annual temperature. It is the type of region we find in coastal Alaska, and the lower section of continental polar North America and Siberia. The tundra is generally snow- and ice-covered except for two or three months. The winters in this region are long and bitter cold, with temperature as low as −35° to −40° in continental regions and −10° to −15° in coastal zones. Cloud forms are very rare since this is a region of subsiding air. The chief weather hazards are the ice crystal fogs of the continental regions and the fogs which roll into the coastal regions in winter. The main hazard to aircraft operation, however, is not the fog, but rather the intense cold which prevails nearly all year. The maintenance problem in this cold weather is indeed obvious. Also such problems as the difficulty in getting fuel to vaporize, etc., is presented in these climates.

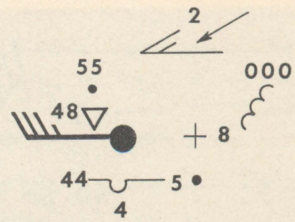
Icecap

The icecap is that region in the polar zone in which the average yearly temperature is less than 32° F. It includes all of Greenland except a narrow southern coastal strip, which is tundra, and nearly all of the land region north of 75° latitude. Also, the frozen sea in the region north of 75° latitude and especially in the immediate vicinity of the North Pole, being so similar to icecap in nature, may be included in this general weather type. Again, as in the case of the tundra region, the extreme subsidence in the region precludes possibility of cloud forms; however, visibility is often impeded by ice crystal fogs in continental areas and sea fog in maritime regions.

The icecap, as the name implies, is a huge dome of ice which has built up through the ages because of the unbalance of radiation in this region. More heat is radiated than is absorbed, and more ice accumulates than evaporates. These icecaps are often 6 to 10 thousand feet thick and are composed of solid, permanent ice and snow.

The temperatures in the icecap region, especially in continental portions, often fall to −85° F. in midwinter. Temperatures as low as −100° F. have been reported from interior Siberia. Flight operations and maintenance is practically impossible in the icecap region. The area presents little or no hazard to airborne aircraft flying over the region. The air is generally clear and if precautions are taken against the intense cold no difficulties will be encountered. The difficulty lies in landing an aircraft in conditions of poor visibility and also in maintaining, servicing, and starting aircraft in the sub-zero temperatures.

CHAPTER THIRTY-SIX



The Weather Map

With the ultimate goal an all-weather Air Force, proper flight planning and a good working knowledge of the "ways of the weather" are becoming more and more important. Planning an instrument flight requires a pilot to have a clear concise picture of the weather factors that will influence his flight in order that he may safely conduct his aircraft to the destination. Each weather station is equipped to provide the pilot with information relative to the weather along his route. In order for the pilot to understand thoroughly the explanation of the weather that will affect his flight, he should be cognizant of how the weather personnel obtains the information that they impart to him.

The facilities in any weather station should be utilized in a logical sequence. A pilot should be concerned with what has happened, what is happening, and what will happen. The surface weather map enables the pilot to gain information very readily on what has happened, for it is a picture of the past weather.

TIME AND METHOD OF TRANSMISSION

Surface weather maps are transmitted from the WBAN Analysis Center, Washington, D. C. by the "facsimile method." This method of reproduction is made possible by the use of an extensive network of landlines (telephone cables). The original image is picked up by a photo-electric cell and the impulses from this master copy are transmitted to and reproduced automatically by weather stations throughout the nation. With this system in operation, every weather station receives the same map at the same time. This avoids the confusion that has been the result of each station preparing an original map by using teletype coded numbers for reference in plotting information. Observations for the plotting of the surface weather map are taken at 0030Z, 0630Z, 1230Z, and 1830Z, however, because of the time necessary for the collection of data and construction of the map, there is a delay of three hours before the map appears on the chart board of a weather station.

METHOD OF COLLECTING DATA

Each weather station has an observor on duty who, at the end of each six-hour period, prepares and transmits, to the master facsimile station in Washington and to all other weather stations, information necessary for the

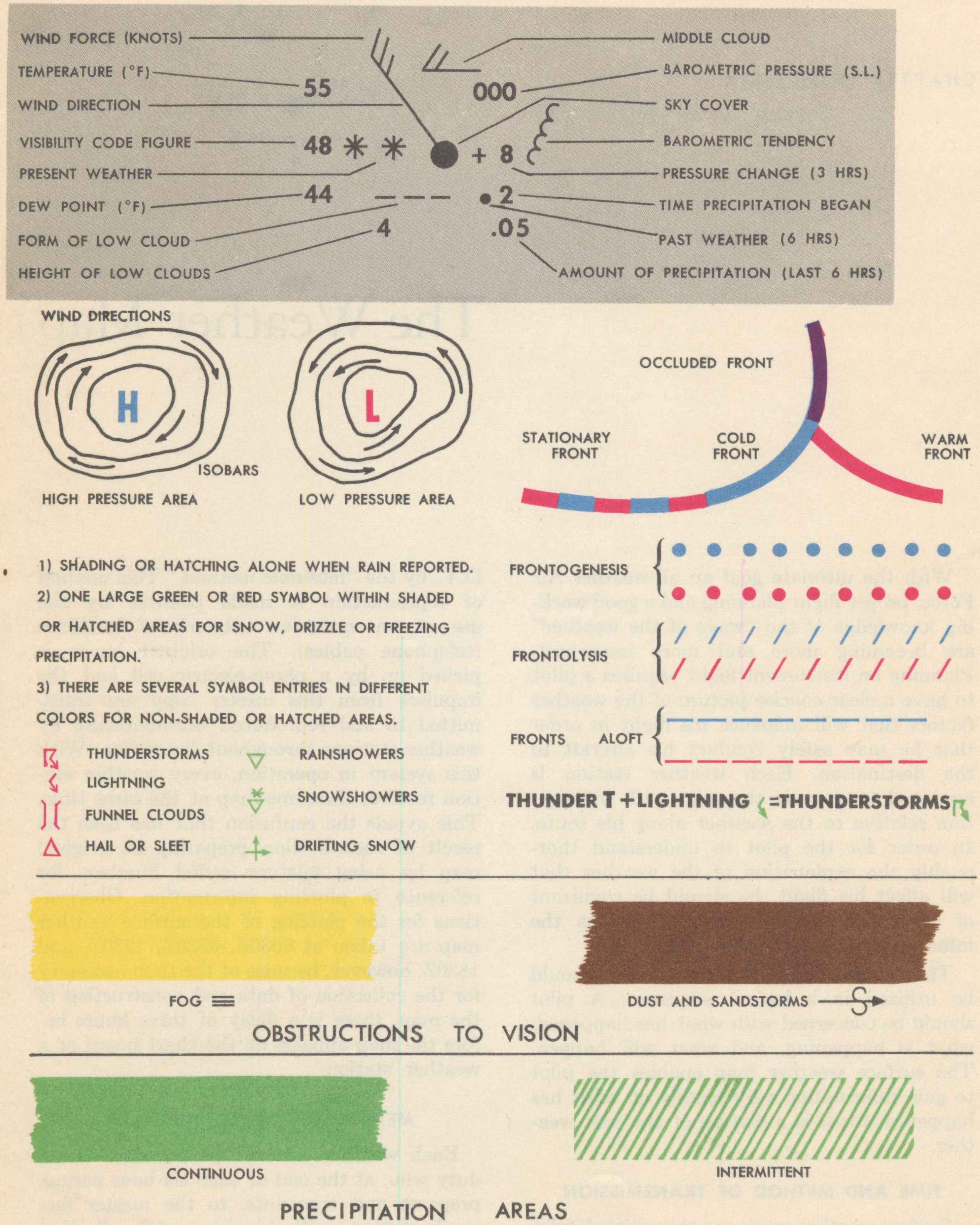
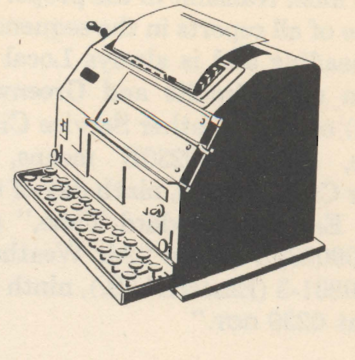


Figure 55—Legends and symbols found on weather map.

Figure 56—Typical facsimile weather map.

CHAPTER THIRTY-SEVEN



Teletype Sequence Reports

Of the many facilities available in the base weather station, the hourly teletype reports are among the most useful for flight planning purposes. The hourly teletype report cannot be used alone but must be used in conjunction with other facilities. It is this integration of facilities that gives the pilot the complete weather picture. The surface weather map presents a broad picture of past weather. The hourly teletype sequence reports may be used to modify this picture as a result of current weather changes.

SYSTEM OF CIRCUITS

All weather reporting stations in the United States are divided into groups. This group of stations is referred to as a circuit. Approximately 12 complete CAA and 2 Air Weather Service circuits are available. There is a relay station in every circuit which is interconnected with relay stations in other circuits. Each relay station is responsible for the selection of information of importance from each of the other circuits.

STANDARD METHOD OF DISPLAY IN WEATHER STATIONS

In the weather station, teletype sequence reports are displayed on a rack and are arranged according to circuit number. Each circuit is placed on a clipboard. Permanently attached to the board is a numerical list of station identification letters for each circuit and the full station name. The circuits are also identified by color; each clipboard, containing one circuit, has a colored band. A planning chart of the United States is located near the circuit board. All of the stations reporting weather are on this chart. So that they may be quickly located, a small colored plastic disc or square, corresponding to the proper circuit, is placed over each station.

TYPES OF TELETYPE SEQUENCE REPORTS

The Hourly Report

Every hour on the half hour all stations within each circuit make weather observations which are transmitted to the relay station. Each station has an assigned place in the cir-

cuit and must transmit in the proper sequence. The time of all reports in the sequence is given in the heading and is always Local Standard Time on CAA Circuits and Greenwich Civil Time (Z) on Air Weather Service Circuits; for example, AW8 090230E means, "Airway Weather Circuit No. 8, ninth day of the month at 0230 Eastern Standard Time," and AWUS 9891-3 090230Z means "Air Weather Service Circuit 9891-3 (Eastern U.S.), ninth day of the month at 0230 GCT."

The Special Report

If there has been a significant change in the weather since the last observation, a special report is transmitted. Special reports are numbered consecutively from midnight, local time; for example, S1, S2, S3, S4, and so on.

If the change in the weather takes place close to the time of observation of the scheduled hourly sequence report, this information is sent as part of the regular sequence.

Example: SHV S5 E40⊕8 210/75/65 ↑↖ 10/015

(Note the inclusion of S5 even though this observation is sent as part of the regular sequence.)

If the change takes place at a time other than that of the regular hourly report, the special report is sent as follows: SHV S6 230545C M3⊕11/2RW 201/70/69 → 14/012

(The time of observation in this case is indicated as 0545C.) Remember that Local Standard Time is used by Civil Stations and GCT is used by Air Weather Service Stations.

The Delayed Report

If for some reason an hourly report is not sent at its regular place in the sequence, it is sent as a delayed report. A delayed report is indicated by the letters "PDW" and the "Date-Time" group, as follows: PDW SHV 230742C E50⊕10 220/65/55 ↓ 10/017 (Air Weather Service Stations use GCT.)

The Correction Report

When a report is in error, a correction is sent and is indicated by the inclusion of the letters "COR" plus the "Date-Time" groups, for example: COR SHV 252230C E25⊕10 176/70/65 ↗ 12/004 (Air Weather Service Stations use GCT.)

SAMPLE TELETYPE WEATHER REPORT

BAD 15⦶ E30⊕2R-F 152/58/57 →↘ 8/996 05164 10332

BAD — *Identification* (Barksdale Air Force Base)

15⦶ — Low clouds at 1500 feet, scattered sky condition.

E30⊕ — *Estimated ceiling* (3000 feet). Overcast sky condition. The ceiling value will always be identified by a letter prefixed to it. These letters indicate the manner of observation or the type of ceiling. They are as follows:

P — Precipitation	E — Estimated
A — Pilot Report	M — Measured
W — Indefinite	B — Balloon

Sky condition symbols are:

○ Clear (less than 1/10 clouds)

⦶ Scattered (1/10 - 5/10 clouds)

◍ Broken (6/10 - 9/10 clouds)

⊕ Overcast (More than 9/10 clouds)

-X Partial obscuration (Sky or clouds visible)

X Obscuration — Obscuration means only one thing — the sky or upper clouds are hidden by precipitation or obstructions to vision (smoke, haze, or fog) on the surface. An obscuration (X) constitutes a ceiling and the method of measurement and height are given. A partial obscuration (-X) does not constitute a ceiling and no height is given.

In cases where several cloud layers are present they will be reported in ascending order of height from left to right. The height of each layer is reported in hundreds of feet and will always precede the sky condition symbol.

A thin cloud layer (a minus sign precedes the sky symbol −⦶, −◍, −⊕) is not classified as a ceiling if more than 5/10 of the sky or higher clouds are visible through the thin cloud layer. A cloud layer may be reported as variable in height. The letter "V" will appear following the cloud height in the sequence report. The degree of variation will be indicated in the remarks portion of the report.

A plus sign (+) may precede the sky symbol when the cloud is dark and threatening.

2 — *Visibility* (2 miles). Visibility is reported in fractions of miles from 0 to 3, in miles from 3 to 15 and every 5 miles above 15. There is no limit to determine maximum visibility; for example, a mountain may be visible for distances up to and more than 150 miles. If the letter "v" follows the visibility figure, the visibility is variable, and the degree of variance will be indicated in the remarks portion of the sequence report.

NOTE

Effective 1 July 1952, visibility will be reported in tenths of nautical miles from 0 to 3 miles, in 0.5 miles from 2 to 3 miles, in whole miles from 3 to 15, and every 5 miles above 15.

R — *Weather* (Light Rain). Other types of weather found in teletype reports are:
TORNADO or WATERSPOUT (always written out in full)

T+	Heavy thunderstorm
T	Thunderstorm
RW	Rain showers
L	Drizzle
ZR	Freezing Rain
ZL	Freezing drizzle
E	Sleet
EW	Sleet showers
S	Snow
SW	Snow showers
SP	Snow pellets
SG	Snow grains
IC	Ice crystals
A	Hail
AP	Small hail
Q	Squall (reported with the wind information)

A plus sign appears after symbols for precipitation and squalls to indicate a heavy degree of intensity and a minus sign to indicate a light degree; a double minus means very light; the absence of any sign indicates moderate intensity. Thunderstorms are reported as either heavy or moderate.

F — *Obstruction to vision* (Fog). Other obstructions to vision are:

GF — Ground fog	BS — Blowing snow
IF — Ice fog	BD — Blowing dust
H — Haze	BN — Blowing sand
K — Smoke	GS — Drifting snow
D — Dust	

152 — *Barometric pressure* (1015.2 mbs). This is reported in tens, units, and tenths of millibars. Prefix "9" or "10" to obtain value.

58 — *Temperature.* (58 degrees F) Temperature is always given in Fahrenheit.

57 — *Dew point.* (57 degrees Fahrenheit.)

↘8 — *Wind direction and speed.* Surface wind is reported in knots on Air Weather Service circuits and in miles per hour on civilian circuits.

NOTE

Effective 1 July 1952, Civil Stations will also report wind speeds in knots.

Arrows indicate the direction *from* which the wind is blowing.

Peak speed of gusts will be reported following the average wind speed (which will be in the usual position) and separated by a "+" sign. If squalls are occurring, "Q" will be used instead of "+."

996 — *Altimeter Setting.* 29.96 inches of mercury. Prefix "2" or "3" to get desired value.

05164 10332 — *5 digit group* (*Terminal Forecast*). Not found on CAA reports.

USES OF THE TELETYPE SEQUENCE REPORT

By using the teletype weather reports in conjunction with the surface map, the airman can locate the present position of a front shown on the map by noting when frontal passage occurs at stations ahead of the old frontal position as shown on the surface weather map. Frontal passages are usually indicated on the teletype reports by changes in pressure, wind direction, and temperature-dew point. The following is an example of cold-front passage.

(1330E) MKC B12⊕7 012/64/52 ↑↗ 18/987
(1430E) MKC 4⦶E15⊕3TRW-012/55/42 → 20+30/990
(1530E) MKC E30⊕15 025/50/35 ↓↘ 20+32/993

The following two reports indicate that a warm front lies between Lake Charles (LCH) and Monroe (MLU).

LCH E40⦷10 997/62/58 ↑↗ 12/951
MLU B5⊕1L-F 995/55/54 ← 10/950

The teletype sequence report also enables the airman to find the type of weather associated with the front, ahead and behind the surface position.

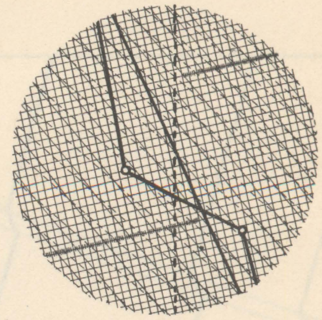
When the adiabatic diagram is used, the teletype sequence report acts as a check against the clouds, or lack of clouds, found on the diagram. The teletype sequence report indicates the bases of the clouds while the adiabatic diagram gives the tops, types, and stability. By checking the temperature-dew point spread, wind velocity, time of day, and cloud cover, the possibility of radiation fog formation can be determined.

The possibility of fog from other sources can also be noted. In the following example the temperature-dew point spread is small and precipitation is occurring. A good chance for fog formation exists.

22 0230C
CHI P25⦷3R-098/58/57 ↓↘ 4/990

In every case the teletype sequence reports give the airman an indication of the existing weather along his route. These reports show existing weather and not forecast weather. The type of flight plan to be filed depends both on the existing and forecast weather along the route and at the destination. The choice of an alternate, if necessary, also depends upon the existing and forecast weather. The airman should check the existing weather along and on both sides of the route, noting the possibility of any hazard developing. In order to be able to do this, he should keep in practice by reading teletype weather reports in the weather station as often as possible. Teletype weather reports are only one of the facilities of the weather station and are of little value when used without reference to the remaining wealth of facilities at his disposal.

CHAPTER THIRTY-EIGHT



Adiabatic Diagram

No single weather station facility is of any great value by itself in weather analysis work. Most of the various weather charts present horizontal weather pictures covering a certain geographical area. The adiabatic diagram shows a vertical picture of the atmosphere over any one particular station. This diagram is of utmost importance in tying together that information which is displayed on the various height and pressure-level charts.

INFORMATION SHOWN ON ADIABATIC DIAGRAM

A vast amount of significant data is obtainable from the adiabatic diagram. This information when used in conjunction with other available facilities is most useful in forecasting and briefing for flight operations. Some of the most important information obtainable from the facility is as follows:

The current adiabatic diagram used in Air Weather Service gives the dew point instead of the relative humidity. To find relative humidity at any point in the free air curve, it is necessary to find the mixing ratio at the dew point and divide it by the saturated mixing ratio at the temperature point. Multiply by 100 to convert to percentage.

Height and Type of Clouds

This information may be obtained directly. Clouds will be present at any layer in the air aloft which shows a relative humidity of 85 per cent or more.

The type of clouds present depends on two things: the stability of the air at the layer at which clouds are indicated, and the height at which this layer shows up. For instance, since the prefix "alto" is used in describing all clouds in the middle-level cloud group, an indication of 85 to 100 per cent relative humidity for a layer from 8,000 feet to 9,000 feet, with a lapse rate less than the moist adiabatic indicating stability, will be alto-stratus clouds.

Turbulence

Rough air or turbulence and associated results will be indicated on the diagram by directly observing the lapse rate of the air mass in question. For unsaturated air a lapse rate greater than the dry adiabatic lapse rate indicates instability, for saturated air a lapse rate greater than the moist adiabatic indicates instability. The greater the instability the greater the turbulence.

Icing Level and Type of Icing

Icing may be expected at any level at which

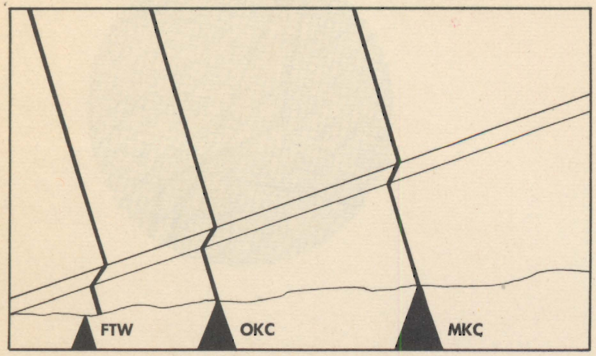


Figure 58—Raobs in determining warm frontal slope.

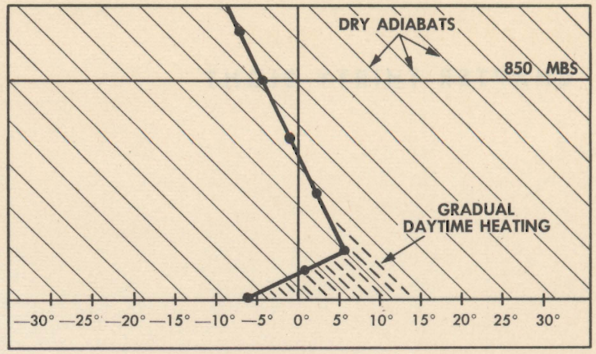


Figure 59—Forecasting max. and min. temp.

visible moisture is indicated at temperatures of freezing or below. However, icing will be most probable where visible moisture is present between 0° and −10° centigrade.

The type of icing depends upon the stability of the layer. Rime ice is associated with stable air. Clear ice is found in unstable air.

Position of Frontal Surfaces Aloft

Frontal surfaces will be indicated as inversions on the adiabatic diagram. Other inversions indicated on the diagram, also, are subsidence and surface inversions. Frontal inversions are distinctive from subsidence and surface inversions because more moisture will be indicated and moisture increases in going aloft through the inversion layers.

Frontal slope may be checked by using the soundings in conjunction with the surface chart. A front indicated at the surface for one station will be indicated aloft over a second station and further aloft over a third station as you move back into the cold air. By joining these three points the slope of the front may be determined. (Fig. 58.)

Forecasting Visibility

Surface visibility and visibility at flight altitude may be determined and forecast by using the adiabatic diagram in conjunction with past surface data. If a surface inversion is indicated on the adiabatic diagram for a particular station, it is reasonable to assume that the surface visibility will be poor. The visibility becomes better during the day with surface heating and worse at night as a result of nocturnal radiation. The exact visibility may be determined by checking the visibility at that station at the same time the day before, or by checking the past visibility for other stations in the same relative position in the air mass. Relative visibility at flight altitudes may be determined by noting the stability conditions aloft for the particular layer concerned.

FORECASTING MAXIMUM AND MINIMUM TEMPERATURE

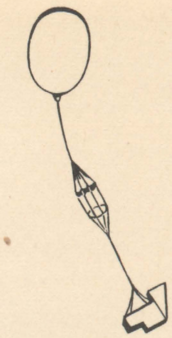
Maximum Temperature

Maximum temperature forecasts can be made for any particular day by making use of the morning sounding in conjunction with other information. The heat from insolation goes into the establishment of an adiabatic lapse rate near the ground. With increased insolation the next higher adiabat is reached. This process continues with continued insolation (see Figure 59). The amount of insolation expected with clear skies for any particular day has been calculated and is available in tables. By using these tables the maximum temperature can be forecast for any particular day. Adjustment must be made for expected cloud cover and expected warm or cold air advection.

Minimum Temperature

Minimum temperature is forecast by noting the amount of radiation for the preceding day at a station in the same relative position and in the same air mass. This information, together with data regarding possible cloud cover and possible warm and cold air advection obtained from upper-air charts, may be used in making accurate forecasts of minimum temperature.

CHAPTER THIRTY-NINE



Winds Aloft

In order to navigate accurately during the long-range, high-speed, high altitude flights which the Air Force is featuring, it is necessary for the aircrew to know the winds aloft. A knowledge of the winds aloft makes possible an accurate ETA, and universal use of winds-aloft data enables the weather officer to forecast winds aloft more accurately.

METHODS OF OBSERVATION

At present, there are two basic methods of obtaining winds-aloft data. The first, and by far the most universal of these, is the pilot balloon observation (PIBAL), and the other is the radiosonde wind (RAWIN) which is obtained as an integral part of the regular radiosonde observation (RAOB).

Pibal (pilot balloon observations)

In this type of observation a hydrogen-filled balloon is allowed to rise freely. The ascent is observed with an instrument, similar to the surveyor's transit, known as a theodolite. Since the balloon rises at a predetermined rate, its height or altitude is known at the end of any time interval. For instance if the balloon rises at 500 feet per minute for the first 2,000 feet, then at the end of two minutes of ascent its altitude is 1,000 feet, etc. The theodolite used in the observation is free to move in both the vertical and longitudinal axes so that the balloon may be tracked in both direction of drift and angle of elevation. From the direction in which the balloon is observed to drift, the actual wind direction may be computed. (Fig. 60.)

The wind velocity is determined indirectly from the angle of elevation of the balloon and is also measured by means of the theodolite. In the case of a strong wind, the angle of elevation (angle 1, Figure 61) of the theodolite will be less, whereas in the case of a calm the angle of elevation (angle 2, Figure 61) will be greater. By use of this relationship the velocity of the wind is readily computed.

In summary, the PIBAL is merely a visual observation of wind direction and speed obtained by tracking the ascent of a free balloon. The obvious disadvantage of this method is the fact that the moment the balloon is lost from sight the observation must be terminated and no further data are available above that level. This causes the winds-aloft charts to be nearly void of data in certain areas. Pibal observations are made 4 times a day.

Figure 60.

Rawin (Radiosonde Wind Observation)

Weather stations having radiosonde facilities also obtain winds-aloft data by using standard radar tracking equipment and a radar reflector in conjunction with the regular radiosonde flights. These observations are called RAWINS.

One method of RAWIN observation is to attach a radar reflector to the radiosonde transmitter unit and then track this reflector by radar as it rises freely with the balloon. The computation of wind direction and velocity in this case is very much the same as in the case of the PIBAL observations. The radar equipment takes the place of the theodolite. The advantage of this type of observation is the continuous availability of the data regardless of visibility and cloud cover.

The current method of collecting wind data by use of radio equipment is the RDF wind observation. In this case the small moisture, temperature and pressure transmitter which is attached to the balloon is tracked by radio direction finding (RDF) equipment. This method is more satisfactory than radar. It has the same advantage of operating in the same low ceiling, poor visibility conditions as the radar method.

RAWIN data, as previously stated, are an integral part of the standard Rawinsonde Rawinsonde code containing all upper-air information. For the purpose of this discussion it is suf-

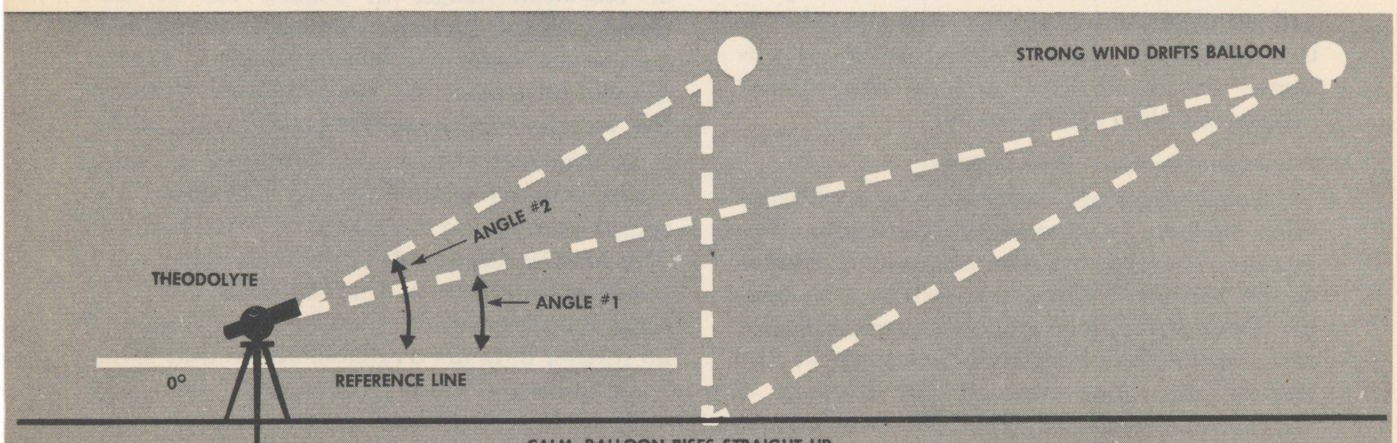


Figure 61—Effect of wind velocity on elevation angle.

ficient to state that the RAWIN section of the Rawinsonde/Rawinsonde code is based upon the same standard grouping as the upper wind code for Pibals and follows the pressure-moisture-temperature group for each level reported.

PLOTTING WINDS ALOFT

Wind information is plotted on the winds-aloft chart by using what is known as a barb and pennant system. An example of this type of wind scale is indicated below.

In the diagram the large flag indicates a velocity of 50 knots, the full barb indicates 10 knots, and the half barb indicates 5 knots. The direction of the wind is indicated by the staff pointing into the station circle from the direction that the wind is blowing using the nearest longitude line as north. Therefore, in the diagram above, we find the wind to be from 300° at 65 knots.

METHODS OF TRANSMITTING WIND INFORMATION

Wind information is sent out on the standard teletype circuits in two separate sets of codes. The first is the upper wind code; the second is part of the Rawinsonde/Radiosonde code. PIBALS are observed at 0300Z, 0900Z, 1500Z, and 2100Z and sent out shortly thereafter. RAOBS are observed at 0300Z and 1500Z and the RAOB messages are sent out at 0600 and 1800Z, respectively. (Central time may be determined by subtracting six hours from Greenwich).

The upper wind consists of the station call letters, the time of observation, surface wind data and the wind data for standard levels above sea level. A typical upper-wind code follows:

SHV22 01608 1714 21816 1820 42022, etc. SHV are the station call letters for Shreveport, La.; 22 indicates the time of observation in Greenwich time to the nearest hour. The rest of the code contains four- and five-figure groups used alternately to the 10,000-foot level. The group starting with zero always indicates surface wind; the 16 indicates a wind from 160°, and the 08 indicates the speed in knots. Thus, the surface wind at Shreveport at 2200Z was from 160° at 8 knots. The following four-figure group indicates the intermediate odd thousand-foot levels; the next five-figure group indicates the next even thousand-foot level, in this case 2,000 feet, etc., to 10,000 feet. From 10,000 feet to 20,000 feet, the codes are sent only for each successive 2,000-foot level. Above 20,000

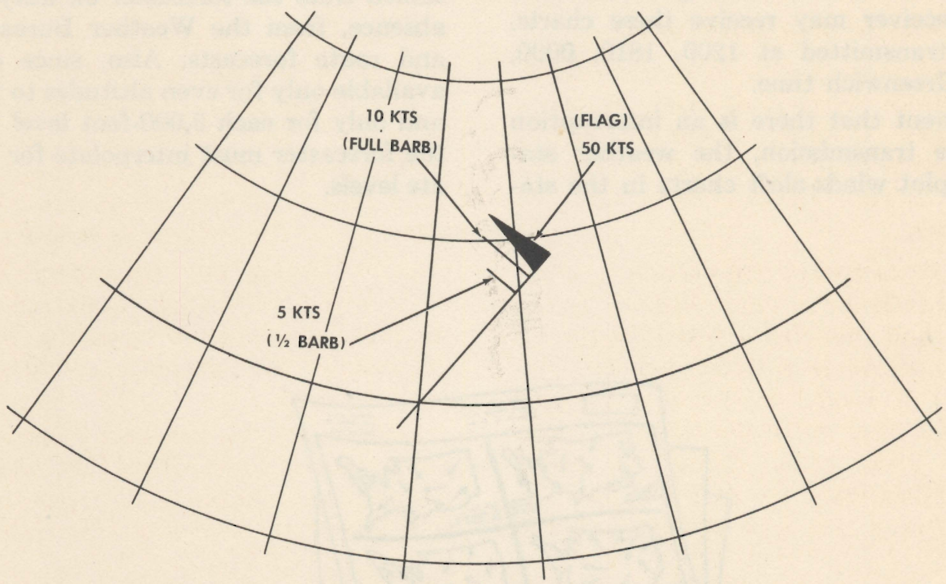


Figure 62—Winds-aloft plot using modified beaufort scale.

feet, 5,000-foot levels thus, according to the above code the winds over Shreveport are: Surface, 160° at 8 knots; 1,000-foot level, 170° at 14 knots; 2,000-foot level, 180° at 16 knots; etc.

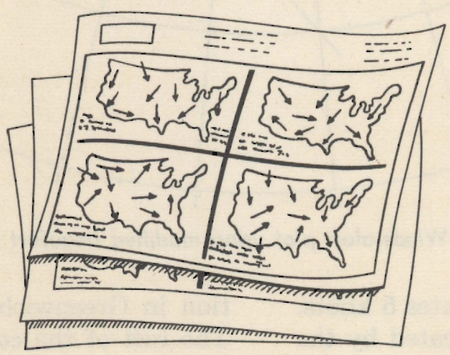
TYPES OF CHARTS

There are two basic forms for the presentation of wind data. The most widely used method is that of the facsimile chart which is plotted from the standard wind in the joint Weather Bureau, Air Force, Navy Analysis Center in Washington, and then sent out on facsimile relays to the individual weather stations. Each station having a standard facsimile receiver may receive these charts. They are transmitted at 1200, 1810, 0000, and 0610 Greenwich time.

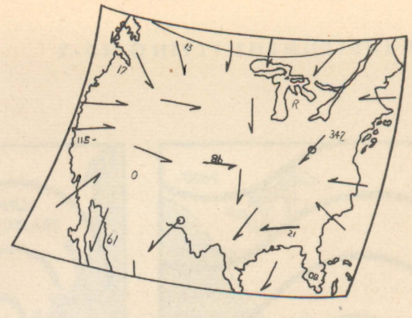
In the event that there is an interruption in facsimile transmission, the weather station must plot winds-aloft charts in the station from the standard wind codes. These charts are plotted according to the same plan as the facsimile charts except that the standard station winds-aloft chart is larger than the standard fascimile chart.

USE OF CHARTS

The winds-aloft charts indicate the winds at the specified time of observation and are not forecast winds. The winds indicated on the chart are always at least 2 hours old and often as much as 8 hours old, therefore it is readily seen that for accurate wind data a forecast of present or future winds must be obtained from the forecaster on duty or, in his absence, from the Weather Bureau regional and route forecasts. Also, since charts are available only for even altitudes to 20,000 feet and only for each 5,000-foot level thereafter, the forecaster must interpolate for intermediate levels.



CHAPTER FORTY



Upper-Air Charts

The purpose of the upper-air chart is to indicate the general circulation aloft by diagramming the fluctuation in the height of the particular pressure level involved. The height variations are plotted for a constant pressure. For this reason upper-air charts are often called constant-pressure charts. These charts are drawn for pressure levels of 850, 700, 500, 300, and 200 millibars.

If the height at which a barometer reads 850 mb. over one station is 5,200 feet, while the height of a barometer at 850 mb. over a second station is only 4,800 feet, the pressure aloft over the first station is greater than that over the second station, assuming constant temperature. When lines are drawn on a chart between stations having the same height for that standard pressure level (850 mb), these lines actually form height contours, but they may be used in much the same manner as isobars, and the flow of the air aloft is streamlined to them.
chart requires knowledge of the fact that for any given latitude and season, the greater the height of a particular pressure level, the greater the pressure, and the less the height the less the pressure. Normally, the height of a pressure level decreases with an increase in latitude (i.e., toward the poles), but any abnormal dip in the height of a pressure level indicates a low-pressure area; likewise, an abnormal rise in height indicates a high-pressure area for the same latitude.

DATA

Upper-air charts present a source of important information regarding the characteristics of the air aloft at the various chart levels. (All the material presented on these charts is obtained from the standard radiosonde observations). Information pertinent to air layers between chart levels may also be determined by interpolation between 2 or more charts. Some of the data available from upper-air charts are as follows.

Height

The height of a standard, constant-pressure level is entered on the chart to the upper right-hand side of the station circle in a three-figure group representing thousands, hundreds, and tens of feet. Example: On the 500 mb. chart, 918 represents 19,180 feet as the height of the 500-mb. surface over that station. Lines joining stations having standard pressure levels of equal height are drawn at 200-foot intervals as contour lines.

Temperature

The temperature of the free air at the standard pressure level is indicated in degrees centigrade to the upper left-hand side of the station circle. Lines of equal temperature are joined by isotherms at 5° intervals in red pencil or ink.

Dew Point

The dew point of the air at the pressure level involved is plotted to the lower right

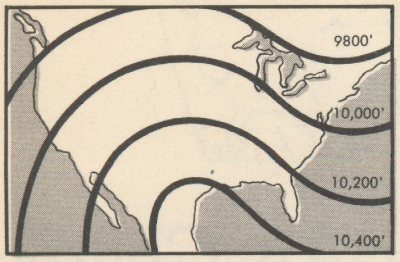


Figure 63—Height lines at 700 mb.

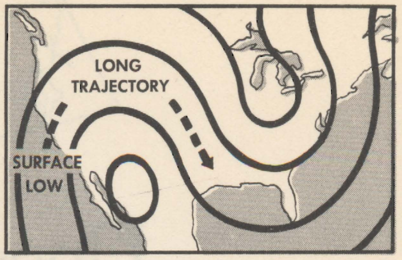


Figure 64—Low-index situation.

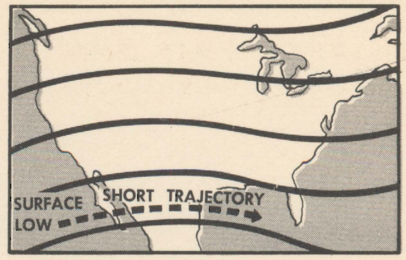


Figure 65—High-index situation.

of the station circle. Green lines connect points of equal dew point. Points where dew point lines cross temperature lines of equal value are regions of saturated air.

Fronts

Fronts are indicated on upper-air charts in the same manner and colors as they are presented on surface charts, if they penetrate the standard level involved.

Trough Lines

Lines connecting points of lowest pressure aloft are called trough lines and are indicated on upper-air charts as solid brown lines.

High-Pressure Centers

High-pressure centers are indicated by the capital letter H stamped at the high-pressure centers in blue.

Low-Pressure Centers

Low-pressure centers are indicated by the capital letter L stamped in red at the low-pressure centers.

Winds

RAWINS winds are indicated on upper-air charts in the same manner as they are on the winds-aloft chart. The winds for the standard chart level are used as follows: The 850-mb. chart shows 5,000-foot winds; the 700-mb. chart shows 10,000-foot winds; the 500-mb. chart shows 20,000-foot winds; the 300-mb. chart shows 30,000-foot winds; and the 200-mb. chart shows 40,000-foot winds. The levels given are approximate.

ANALYSIS OF CHARTS

The upper-air charts are the only source of complete, horizontal coverage for upper-air data. These, in combination with the adiabatic diagrams, give a complete three-dimensional coverage of upper-air information. Weather tendencies and trends are generally more representative aloft than surface data, because air aloft is affected neither by the earth's friction nor by diurnal heating and cooling. The upper-air charts are potentially very useful tools for the forecaster. Areas of cyclonic flow aloft indicate areas of cloudiness moving in at the surface. Some of the forecasting possibilities of these charts and a few of the basic rules to be used in conjunction with them are shown below.

1. If the wind shifts anticyclonically aloft, warm air advection can be expected.
2. If the wind shifts cyclonically aloft, cold air can be expected.
3. Systems which intensify in direction and velocity of circulation aloft are deep and tend to persist.
4. Systems which reverse in circulation aloft are shallow and tend to be transitory.

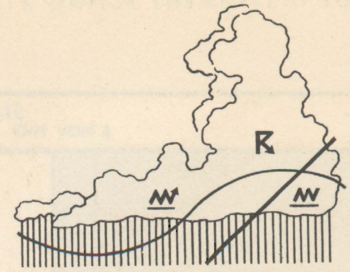
High and Low Index

All closed systems (lows, isolated high cells) move with the air flow aloft. When this flow is oriented so that there are deep troughs and ridges aloft, the systems appear to move slowly from west to east and often stagnate. This is called a low-index situation. When the flow aloft is approximately west to east with only a few ridges or troughs, the closed systems move rapidly from west to east and never stagnate. This is a high-index situation.

Winds Aloft

In the absence of winds-aloft data, it is possible for the forecaster to determine winds-aloft data from the upper-air chart, because the wind-flow aloft is parallel to the height lines on a standard pressure chart.

CHAPTER FORTY-ONE



Vertical Cross Section of Weather

Since a picture is the most useful and graphic method of expressing a weather situation, and since the Air Weather Service utilizes many such pictures, this chapter is devoted to a discussion of two of the many pictures. They are (1) the static cross section and (2) the A. W. S. Form 55-10 or vertical cross-section forecast.

The static cross section can be compared with other picture facilities in the weather office that are available to the pilot. One comparison is with the weather map. The weather map has two major disadvantages which render it inadequate for thorough weather analysis: past phenomena depiction, and surface-observed phenomena. It is therefore evident that supplemental information of a current and future nature, depicting weather along the horizontal and vertical extent of the atmosphere, is needed. One method of gaining this supplemental information is through the use of the cross-sectional diagrams.

STATIC CROSS SECTION

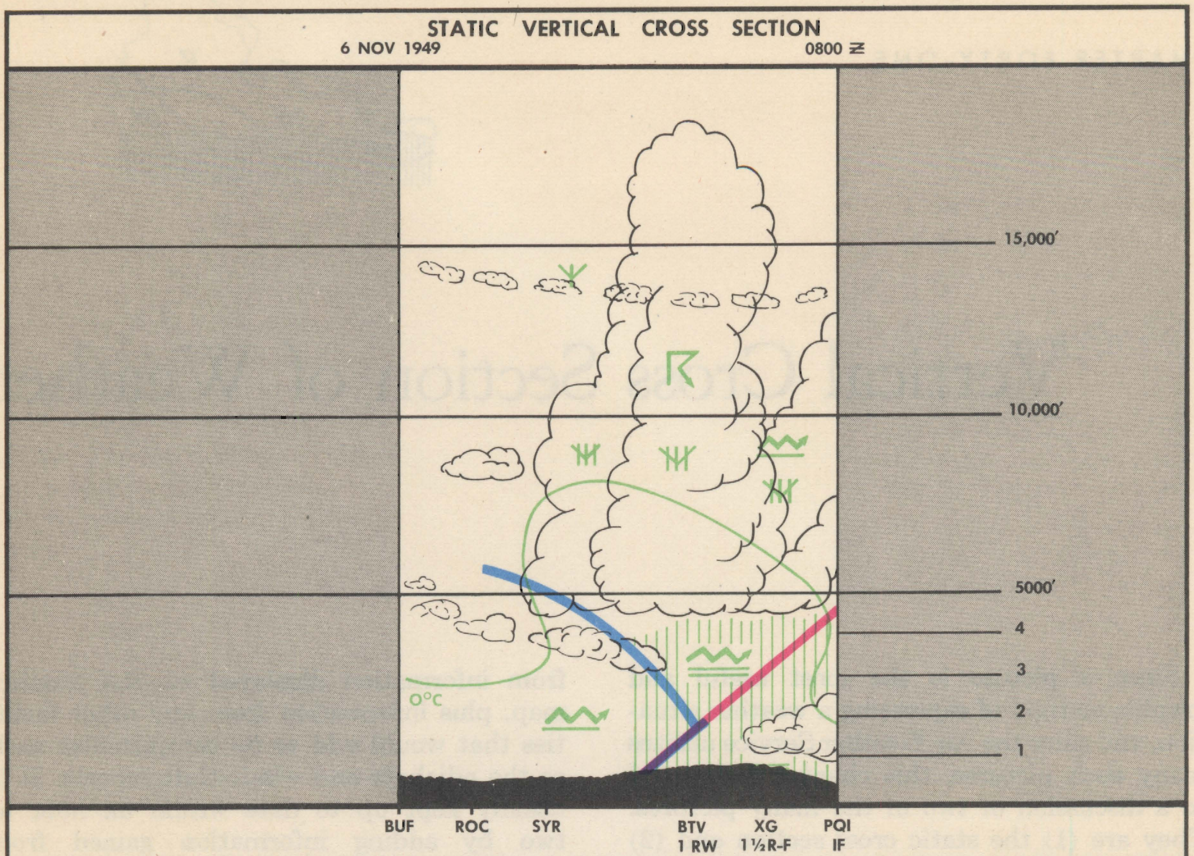
In stations where certain routes are commonly flown, the forecaster may prepare a picture which in some measure minimizes the disadvantages of the weather map. This picture is known as the "static vertical cross section." The cross section is usually prepared from information displayed on the weather map, plus information from any other facilities that would add to its completeness such as the adiabats and winds-aloft reports. It is usually kept up to date within an hour or two by adding information gained from analysis of the hourly teletype reports. The important thing to be kept in mind when the cross section is used is that like other facilities it represents past weather and must not be construed as necessarily representative of weather to be encountered during the flight. The cross section is a picture of weather phenomena that have occurred along a particular route. Among the items included on the static cross section picture are:

1. The route for which the picture is made. This is indicated by the call letters of the stations on or within 25 miles of the route.

2. The altitude scale for the picture. This scale is dependent upon the vertical extent of the weather to be pictured.

3. A terrain-relief cross section showing height of the terrain to be flown over. The pilot should be cautioned against using this terrain information for navigational purposes.

4. Fronts, the location along the route of the surface position of the front and also the slope of the front aloft.



EXPLANATION OF SYMBOLS

RAIN	SNOW	SHOWERS	LIGHT ICING	LIGHT TURBULENCE	BLUE LINE — COLD FRONT
HAIL	FOG	THUNDERSTORM	MODERATE ICING	MODERATE TURBULENCE	RED LINE — WARM FRONT
			HEAVY ICING	HEAVY TURBULENCE	GREEN LINE — FREEZING LEVEL

WINDS ALOFT FORECAST

PORTION OF ROUTE	SURFACE TO 5000′	5000′ to 10,000′	10,000′ to 15,000′	15,000′ to 20,000′	ABOVE 20,000′	PILOT'S REMARKS (PILOT SHOW WIND IF DIFFERENT)
BUF TO BTV	320° 20 KTS	300° 35 KTS	290° 40 KTS			
BTV TO XG	VARIABLE AND GUSTY					
XG TO PQI	140° 20 KTS	107° 30 KTS	220° 40 KTS			

Figure 66.

5. Clouds, cloud types, and the heights of the bases and tops of the clouds.

6. Turbulence, indicated at the level where turbulence will occur by means of a turbulence symbol.

7. The 0° isotherm, the height at which temperatures become 0°.

8. Icing, indicated by icing symbols entered at the levels where icing will be encountered.

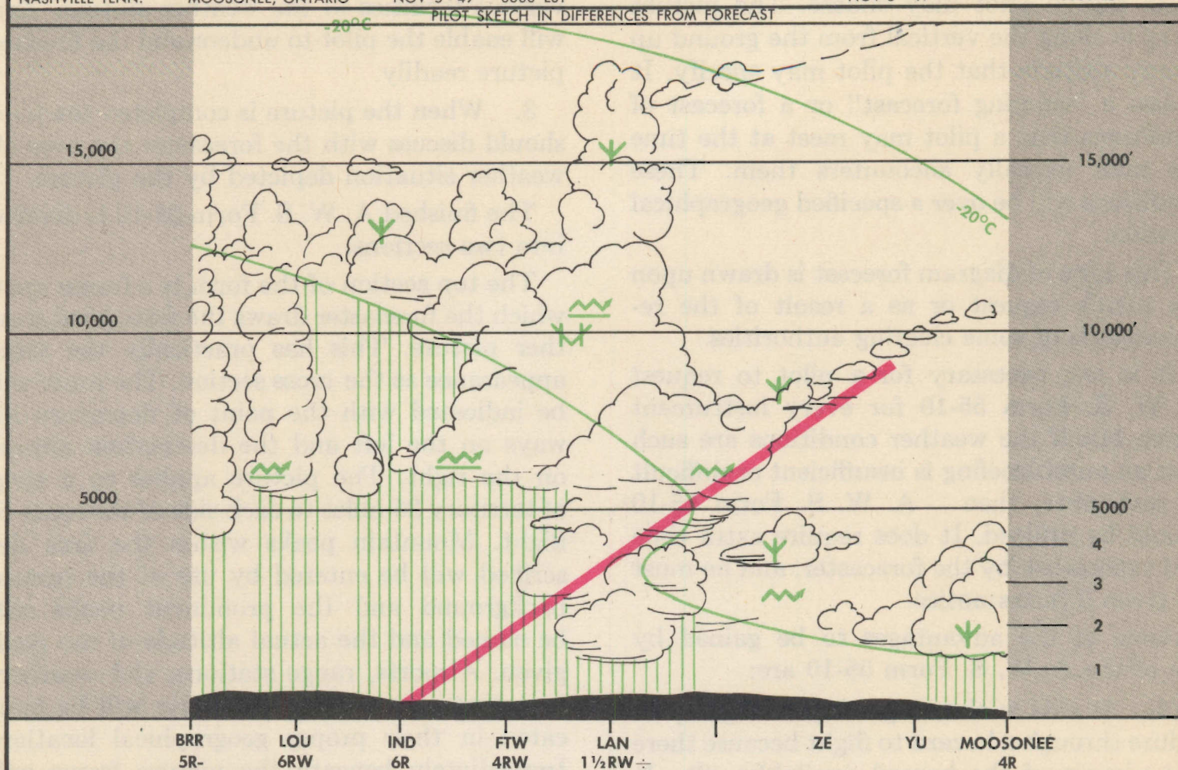
9. Winds-aloft data, indicated by portions of the route and entered in the space provided for winds-aloft data.

10. Surface phenomena, such items as surface visibilities, rain, fog, snow, etc. entered along the lower portion of the picture along with the call letters of the various stations on the route.

See Figure 66 for an example of a completed static vertical cross section.

MAKE IN DUPLICATE WEATHER STATION RETAIN COPY		VERTICAL CROSS SECTION FORECAST			
FROM	TO	FORECAST GOOD UNTIL	FORECASTER	DATE	TIME
NASHVILLE TENN.	MOOSONEE, ONTARIO	NOV 5 - 49 0800 EST		NOV 5 - 49	0030 EST

PILOT SKETCH IN DIFFERENCES FROM FORECAST



EXPLANATION OF SYMBOLS

RAIN	SNOW	SHOWERS	LIGHT ICING	LIGHT TURBULENCE	BLUE LINE — COLD FRONT
HAIL	FOG		MODERATE ICING	MODERATE TURBULENCE	RED LINE — WARM FRONT
THUNDERSTORMS			HEAVY ICING	HEAVY TURBULENCE	GREEN LINE — FREEZING LEVEL

WINDS ALOFT FORECAST

PORTION OF ROUTE	SURFACE TO 5000'	5000' to 10,000'	10,000' to 15,000'	15,000' to 20,000'	ABOVE 20,000'	PILOT'S REMARKS (PILOT SHOW WIND IF DIFFERENT FROM FORECAST)
BRR TO IND	200° AT 20 KTS	230° AT 35 KTS				
IND TO ZE	90° at 20 KTS					
ZE TO MOOSONEE	40° AT 15 KTS	0° at 25 KTS				

Figure 67.

The cross section integrates most of the information in the weather station for the pilot; however, it is confined to a limited sector or route. A pilot should *not* get the impression that a cross section eliminates the necessity of using all of the individual facilities. It will give a generalized picture of a specific weather situation over a confined area, but a pilot must also utilize the other facilities for more detailed information necessary for complete and comprehensive flight planning.

A. W. S. FORM 55-10, VERTICAL CROSS SECTION FORECAST

Another type of cross section is the A. W. S. Form 55-10, Vertical Cross Section Forecast. This is a specific and personalized picture. It eliminates the disadvantages of the other facilities such as the weather map and the

static cross section. It is a forecast that shows the anticipated weather along the proposed route that a pilot may choose. The picture extends along the vertical from the ground up to any altitude that the pilot may specify. It is also a "running forecast" or a forecast of conditions that a pilot may meet at the time the pilot actually encounters them. These conditions will be over a specified geographical location.

This type of diagram forecast is drawn upon the pilot's request or as a result of the requirements of some clearing authorities.

It is not necessary for a pilot to request A. W. S. Form 55-10 for every instrument flight, but if the weather conditions are such that an aural briefing is insufficient or difficult to remember, then A. W. S. Form 55-10 should be utilized. It does require extra time and extra work by the forecaster, and he must be given 2 hours notice.

Some of the advantages to be gained by use of the A. W. S. Form 55-10 are:

(1) It aids in choosing a logical flight procedure through a hazard to flight because there is a picture of the hazard available; (2) It forms a basis upon which a pilot can make a logical change in flight plan; and (3) It enables a pilot to establish his relative position to the weather phenomena to be encountered.

Points to be considered in using A. W. S. Form 55-10.

1. The pilot must furnish the forecaster with the following information.

a. The exact route of flight. (A preliminary study of the weather is a prerequisite for doing this).

b. The altitude at which he intends to fly.

c. The estimated time of departure and the estimated time en route.

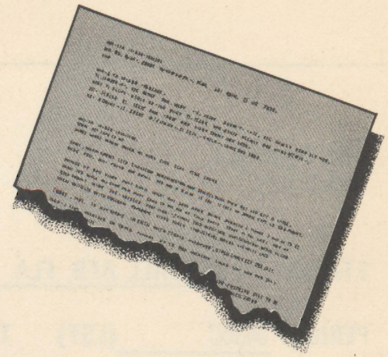
2. While the forecaster is preparing the picture, the pilot should be gaining a background of the weather by perusal of the various facilities in the weather station. This will enable the pilot to understand the finished picture readily.

3. When the picture is completed the pilot should discuss with the forecaster the over-all weather situation depicted by the picture.

The finished A. W. S. Form 55-10 is divided into two sections.

The top section of the form is a frame upon which the forecaster draws the forecasted weather picture. This has practically the same appearance as the cross section. The route will be indicated with the point of departure always on the left and the destination always on the right. The picture applies to a strip of territory 25 miles to each side of the route of flight. Mountain peaks within the area described will be entered by use of the terrain background and the prominent peaks will be named and the actual altitude of the peak given. Airports, range stations, and weather-reporting points along the route will be indicated in their proper geographical location. Immediately beneath the picture frame will be a legend explaining all of the symbols that are used on the picture itself. The lower or bottom portion of A. W. S. Form 55-10 is used to indicate the winds-aloft data and portions of the route for such winds-aloft data. See Figure 67 for a completed A. W. S. Form 55-10.

Since A. W. S. Form 55-10 is kept by the pilot for the duration of the flight, he should note on the form any discrepancies between the forecasted information and the weather he actually encounters. The form should be submitted to the weather station personnel at the pilot's destination along with any discrepancies noted so that the weather station personnel may benefit by his insertions. Other similar forecasts may benefit by the information that the pilot is able to give.



CHAPTER FORTY-TWO

Forecasts

Good flight planning demands a coordinated survey of all weather station facilities. It is particularly important that the pilot have a clear-cut picture of future conditions. It is the job of the duty forecaster to correlate weather data relevant to the requirements of the individual pilot and his mission and to present a forecast for expected weather en route. However, there are many prepared forecasts in the weather station available through the teletype and facsimile services which cover all aspects of weather data. The pilot should be familiar with these and understand their use.

Fundamentally there are two types of prepared forecasts — the written or coded forecast, and the chart type forecast or prognostic chart.

Written Forecasts

The *Local Terminal Forecast* is a written forecast prepared by the station duty forecaster. It is prepared at regular intervals several times a day. It generally accompanies one of the six-hourly synoptic charts and covers a 24-hour period starting from the time of that chart. This forecast covers expected weather conditions in the local flying area at a given base. An example of a local terminal forecast is reproduced in Figure 68.

The *Five Digit Terminal Forecast* accompanies the hourly teletype sequence report emanating from all Air Weather Service Stations. It is a coded forecast and is found in the "remarks" section of designated hourly sequences. (The time that each weather station transmits this type forecast is determined by higher echelons of the Air Weather Service.) It covers a forecast period of at least nine hours. The number of five digit groups used are dependent upon the number of weather changes expected. The basic code form is as follows:

H H V T W

In this code, when five-tenths or less cloud cover is forecast, HH is the height of the lowest clouds for time interval T (see Table 1). When more than five-tenths cloud cover is forecast for time interval T, HH is the forecast height of the ceiling (see Table 2).

Table 1

HH — Height of Lowest Clouds. Sky cover 5/10 or less.	
Code Figure	Cloud Heights Above Surface in Feet
/0	Less than 100
/1	100
/2	200
etc.	etc.
/9	900
1/	1000
2/	2000
etc.	etc.
9/	9000
0/	10,000 or higher

AWS Form 55-7
(Apr 49)

LOCAL TERMINAL FORECAST

STATION TYNDALL AFB, FLA. DATE 31 JULY 51 (LST)

PERIOD 0630C (LST) TO 01/0030C (LST)

FORECAST BASED ON 0630Z Z CHART

GENERAL SITUATION:

THE SOUTHEASTERN U. S. IS UNDER THE INFLUENCE OF SOUTHERLY FLOW FROM THE SURFACE THRU 35,000 FT. THIS IS BRINGING IN THE WARM MOIST AIR FROM THE GULF AND THAT COMBINATION PLUS SURFACE HEATING WILL GIVE SHOWERS AND THUNDERSHOWERS IN THE LOCAL AREA AFTER 1030C THRU 2030C. NOCTURNAL SHOWERS WILL BE BROUGHT IN FROM THE GULF FROM 0430C THRU 0730C THESE SHOWERS WILL DISSIPATE VERY SOON AFTER CONTACT WITH THE LAND. THERE IS A COLD FRONT FROM THE GREAT LAKES THRU CENTRAL OKLA AND STATIONARY BACK THRU MONTANA. THE WESTERN U. S. IS UNDER THE INFLUENCE OF LOW PRESS AREAS.

SKY CONDITION AND CEILINGS:

TYNDALL AND LOCAL AREA — IN THE BEGINNING OF THE PERIOD THERE WILL BE SCATTERED NOCTURNAL SHOWERS FLOATING IN FROM THE GULF. VERY LITTLE RISK OF ONE BEING OVER THE FIELD BUT THEY WILL BE SCATTERED IN THE LOCAL FLYING AREA. BASES 2000 WITH LIGHT TO MODERATE RAIN. OTHERWISE SCATTERED AC & AS 10-12,000 FT AND CI & CS AT 20-25,000 ⦶-⦷. SC & CU FORMING BY 0730C WITH BASES 3-4000 FT AND SCATTERED SHOWERS BY 1030C LASTING THRU 2130C. THE LOCAL TERMINAL WILL BE VFR THROUGHOUT MOST OF THE FORECAST PERIOD. ANY SHOWER WILL BE OF 10-20 DURATION AND THUNDERSHOWERS WHICH WILL BE WIDELY SCATTERED WILL BE OF 30-40 MIN DURATION.

VISIBILITY AND OBSTRUCTIONS TO VISION:

10-MILES WITH EXCEPTION OF THE SCATTERED SHOWERS AND THUNDERSHOWERS AS NOTED WITH VIS REDUCED TO 1-6 MI IN RAIN.

PRECIPITATION, ICING, THUNDERSTORMS, TURBULENCE AND OTHER HAZARDS:

SCATTERED SHOWERS AND THUNDERSHOWERS AS NOTED ABOVE.

FREEZING LEVEL (FEET MSL)

16,000 FT MSL

WIND DIRECTION (DEG. TRUE) — WIND SPEED (KNOTS) — TEMPERATURE (°C)

TIME (LST)	1200C											
	DIR.	SPEED	TEMP	DIR.	SPEED	TEMP	DIR.	SPEED	TEMP	DIR.	SPEED	TEMP
SURFACE	SE	10										
5000 FT MSL	SSW	12	+18									
10000 FT MSL	SSE	15	+10									
15000 FT MSL	SSW	15	+02									
20000 FT MSL	S	12	—08									
25000 FT MSL	S	08	—13									

FURTHER OUTLOOK: LITTLE CHANGE

MAX. TEMP. 88 (F~~°C~~) TIME 1230C MIN. TEMP 77 (F~~°C~~) TIME 0400C

FORECASTER CAPT. WILLIS TIME 0300C

Figure 68. Local Terminal Forecast.

Table 2

HH — Height of Ceiling. Sky cover more than 5/10.	
Code Figure	**Height of Ceiling Above Surface in Feet**
00	Less than 100
01	100
02	200
etc.	etc.
79	7900
80	8000
81	9000
82	not used
83	10,000
84	13,000
85	16,000
86	20,000
87	23,000
88	26,000
89	30,000 or higher
99	No clouds

V is the forecast prevailing visibility for the time interval T. (See Table 3.)

Table 3

V — Visibility	
Code Figure	**Visibility in Statute Miles**
0	0 to less than ⅛
1	⅛ or more, but less than ¼
2	¼ or more, but less than ½
3	½ or more, but less than ¾
4	¾ or more, but less than 1
5	1 or more, but less than 2
6	2 or more, but less than 3
7	3 or more, but less than 5
8	5 or more, but less than 7
9	7 or more

T is the time in hours from the time of the hourly sequence to which the Five Digit Forecast is attached to the time of the first significant change in HH, V, or W. The time T in succeeding groups will be the time, in hours, between the preceding and the next significant change. The forecast indicated in the last Five Digit Forecast group is valid for the remainder of the standard nine (9) hour forecast period. (See Table 4.)

Table 4

T — Time	
Code Figure	**Time in Hours**
0	Within 1
1	Between 1 and 2
2	Between 2 and 3
3	Between 3 and 4
4	Between 4 and 5
5	Between 5 and 6
6	Between 6 and 7
7	Between 7 and 8
8	Between 8 and 9
9	Between 9 and 10

W is the forecast weather for the time interval T. The weather which has the greatest detrimental effect upon the safety of aircraft operation is coded. (See Table 5.)

Table 5

W — Weather	
Code Figure	**Weather**
0	Total sky cover—Clear or scattered clouds
1	Total sky cover—Broken
2	Total sky cover—Overcast
3	High or gusty surface winds
4	Fog or other obstruction to vision
5	Freezing rain or freezing drizzle
6	Rain
7	Snow or Sleet
8	Showers
9	Thunderstorm, with or without precipitation

NOTE

The use of a group ////W indicates the occurrence of hazardous weather phenomena concurrent with W in the preceding group. For example, the two groups 10244 ////5 indicate the occurrence of freezing precipitation as well as a fog.

The code word GRADU means gradually becoming. The group that immediately follows indicates the weather conditions expected after the gradual change.

The code word INTER means intermittent variations. The group that follows INTER

TIME (See Table 4)	BASE OF CLOUDS OR OBSCURATION (See Table 1 or 2)	VISIBILITY (See Table 3)	WEATHER (See Table 5)
0730Z	200 ft.	¼ mi.	Fog
bcmg. between 1030Z & 1130Z	500 ft.	½ mi.	Fog
bcmg. between 1130Z & 1230Z	1000 ft.	¾ mi.	Fog
bcmg. between 1430Z & 1530Z	1000 ft. (Scattered)	1 mi.	Fog
bcmg. between 1630Z & 1730Z	3000 ft. (Scattered)	2 mi.	Fog
bcmg. between 1930Z & 2030Z	Clear	7 mi. or more	none

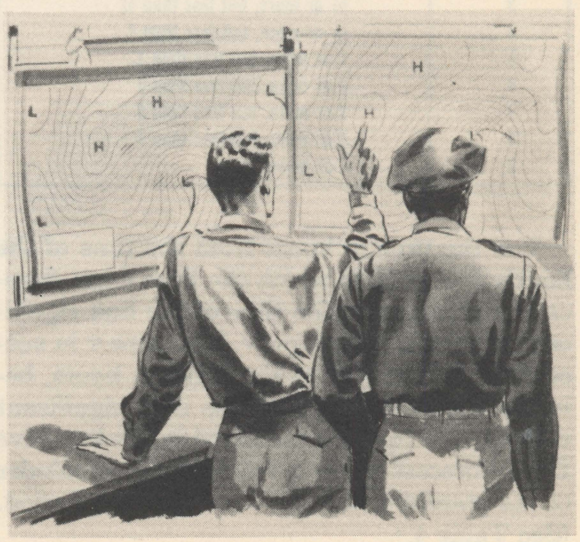
Decoding of Five Digit Forecast.

indicates the weather expected intermittently with the weather indicated by the previous group.

The following teletype sequence for Eglin Air Force Base at 0730Z includes an example of an Air Weather Service five digit terminal forecast: VPS W2X1/4F 998/64/64 ↑↖5/987/ 05334 10414 1/534 3/624 99930

By using the preceding tables you can interpret this Five Digit Forecast. You find that a fog condition is expected to remain at Elgin AFB during the first of the forecast period. It is expected that the condition will gradually improve, finally becoming clear by the end of the forecast period (12 hours after sequence time). The specific decoding of the forecast groups is as shown in the above chart.

The U.S. Weather Bureau Terminal Forecast is available in almost all USAF weather stations and all civilian weather stations in the continental U.S. This forecast is prepared by the U.S. Weather Bureau at the various forecast centers throughout the country. It covers a 12-hour period, the time of which is clearly indicated in the heading in a date-time group form. All major terminal cities along U.S. airways are covered in the forecast. Important forecast data such as cloud bases, sky conditions, precipitation forms, visibilities, types of visibility restrictions, and surface winds are included. Ceilings forecast to be below 20,000 feet are preceded by the letter "c." Sky condition symbols for clouds forecast to be 20,000 feet, or higher, are preceded by a slash — with the expected height omitted. Visibilities expected to exceed 8 miles are omitted, as are winds below 12 mph. When more than one layer of clouds are expected they are indicated in ascending order of height from left to right. The times of expected significant changes are indicated by the inclusion of the times of such changes in the body of the forecast. These forecasts are provided specifically for flight planning purposes. They provide an excellent source of forecast data while in flight (from CAA Communications Stations), in Weather Bureau Stations where forecasters may be off duty, and in military weather stations to supplement the forecasts issued by the duty fore-



```
FTW

FT FTW 181022Z
180500-181700C

FTW-1
TUL MKO ○ ↘14

FTW-2
PNC OKC ○ ↓15+
ICH ○ ↙12
FTW DAL /-⦶ ↓↘14

FTW-3
ABI SJT /-⦶ ↘12
ACT AUS C12⦷ ↘18. 0700C /-⦷ ↓15
SAT 150⦶/-⦷ ↘18. 0830C /-⦷ ↓15
LRD C150⦷ →↘12. 1030C COLD FROPA 150⦶/-⦷ ↓↙18. 1230C /-⦷ ↙14
BRO C18⦷. 1000C C25⦷. 1330C COLD FROPA C30⦷ ↓↙15. 1500C 35⦶/-⦷ ↙15
CRP C18⦷. 0830C COLD FROPA C30⦷ ↓↙18. 1130C 35⦶/-⦷ ↙15
GLS BUJ 12⦶C30⦷ →12. 0700C COLD FROPA C35⦷ ↓↘18+. 0900C 40⦶/-⦷ ↘15
HOU 12⦶C30⦷ →12. 0600C COLD FROPA C35⦷ ↓↘18+. 0900C 40⦶/-⦷ ↘15
DRT 150⦶/⦷. 0700C COLD FROPA 150⦶/-⦷ ↙15
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Figure 69. Terminal Forecast.

caster. An example of a Weather Bureau Terminal Forecast is shown in Figure 69.

The sample Terminal Forecast shows the group of Weather Bureau Terminal Forecasts emanating from the Fort Worth forecast center. This forecast was transmitted at 1022 Greenwich time on the eighteenth day of the month. It is valid from 0500 until 1700 Central Standard time, same day. For an example of interpretation, refer to CRP, Corpus Christi, Texas. Literally, it reads as follows:

> "From 0500C until 0830C this station will have a ceiling at 1800 feet, broken. (At this point it must be understood that because visibility and wind are not mentioned, the visibility will exceed 8 miles, and the wind will not exceed 11 miles per hour.) At 0830C, there will be a cold frontal passage with a ceiling at 3000 feet, broken, with winds NNE at 18 mph. This condition will prevail until 1130C when it will become 3500 feet scattered, with a thin broken layer above 20,000 feet, and winds becoming NE at 15 mph."

Prognostic Charts

The various types of surface and constant pressure (upper air) charts available in the base weather station were discussed in Chapters 36 and 40. It is also possible to construct weather charts which will become valid at some predetermined future time. These charts are called prognostic, or "prog," charts. The verifying time in the legend on each chart is the time that the weather situation depicted on the chart is expected to occur. They resemble those corresponding surface and/or constant pressure charts that were used as a basis for the forecast chart, except that they are lacking in plotted data.

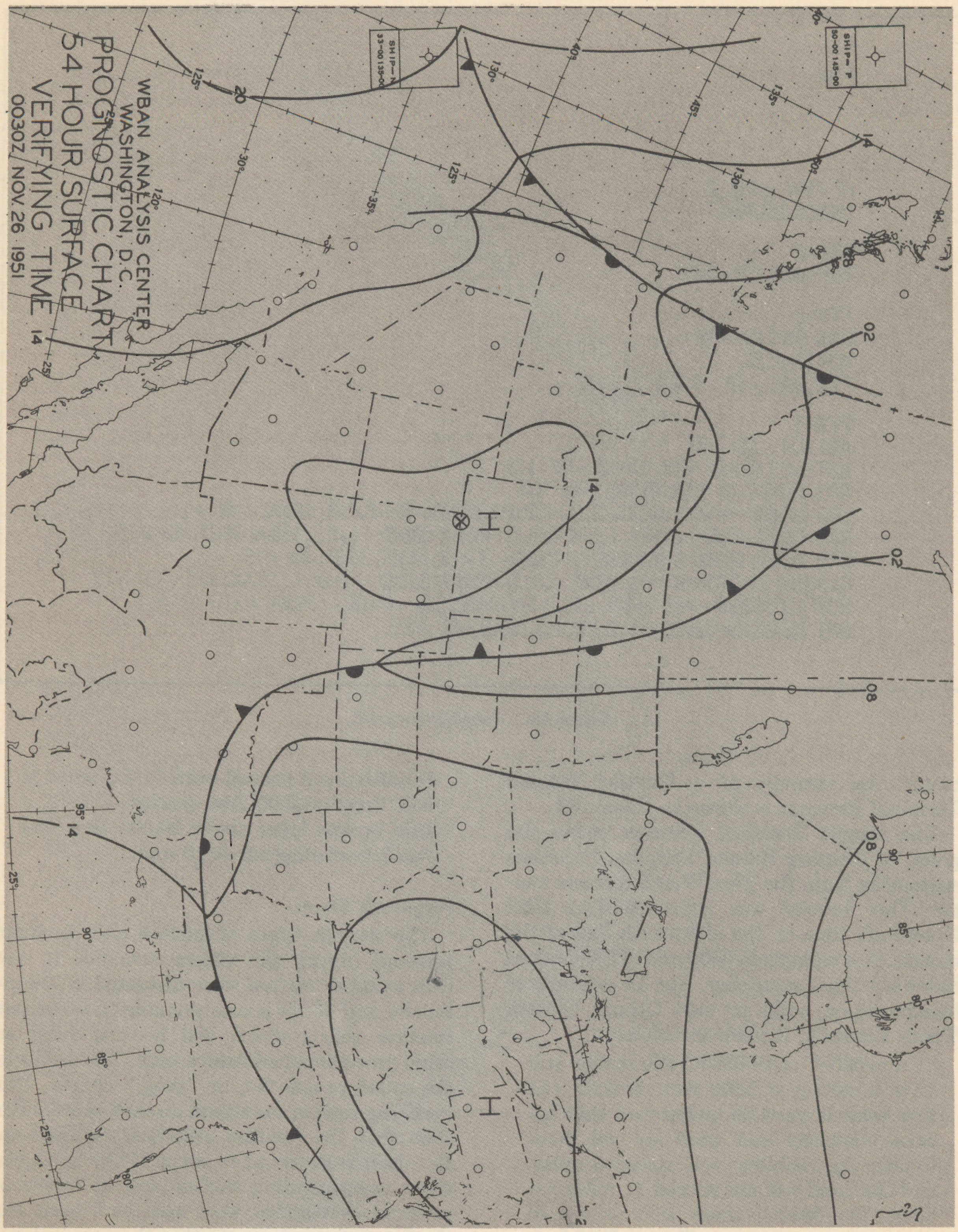
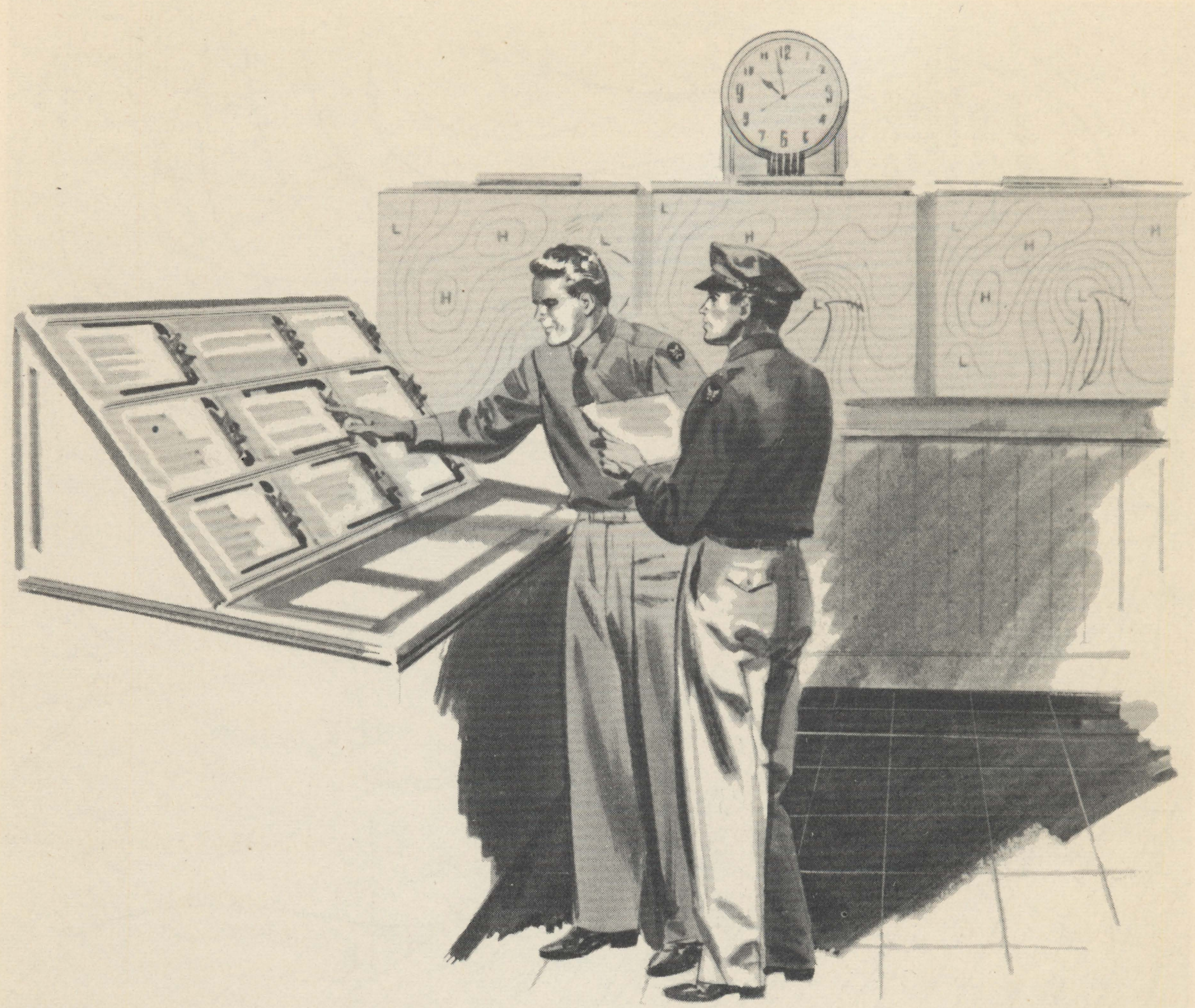


Figure 70. Prognostic Chart — 54 Hour Surface



Some of the prognostic charts available in USAF weather stations are as follows:

30 hour surface (combined with the 36 hour 700 mb contour "prog")

54 hour surface

18 hour 500 mb contours and 300 mb winds

36 hour 500 mb contours and 300 mb winds

18 hour 200 mb contours and 150 mb winds

36 hour 200 mb contours and 150 mb winds

The surface prognostic charts indicate further: pressure pattern, positions of high and low pressure centers, fronts, and types of fronts. The expected progress of moving weather systems may be readily noted from these charts.

Constant pressure prognostic charts are useful in determining future pressure pattern and winds aloft. They are especially useful for flight planning purposes since they provide an easily understandable and reasonably accurate source for winds aloft data for the level concerned.

Each of these forecast facilities has its own specific use. Used together they present a very comprehensive survey of all available forecast data. Used properly, and with the assistance of the station forecaster, they aid materially in proper, business-like flight planning.

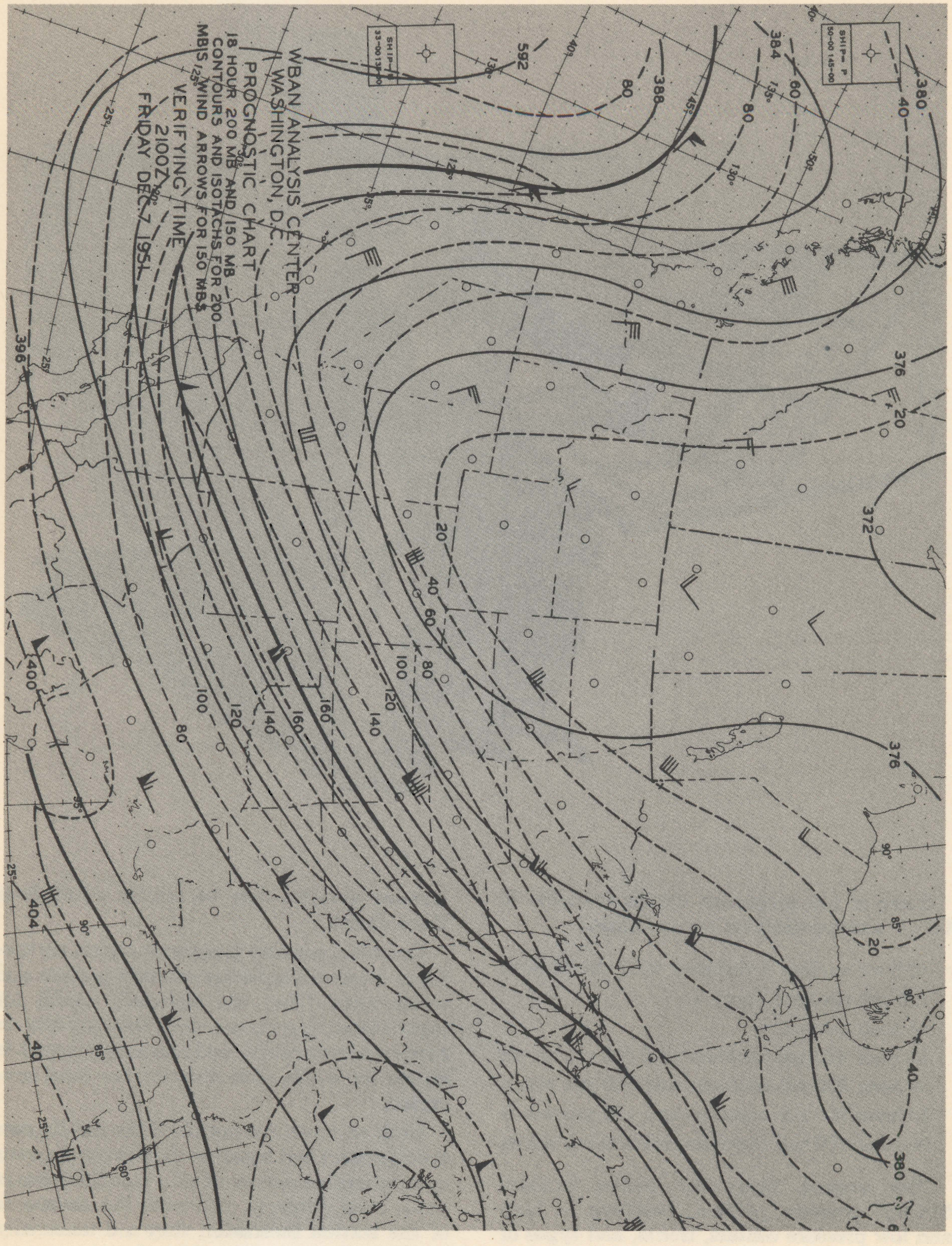
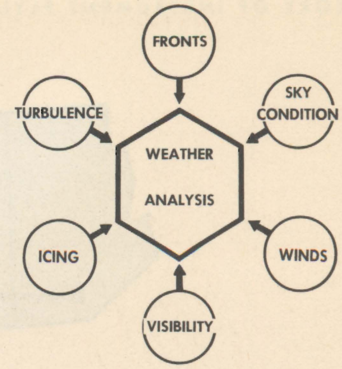


Figure 71. Prognostic Chart — 18 Hour 200 Mb. Contours



Correlation of Facilities

No one chart or facility, nor one series of charts or facilities is of any great value alone in preparing a forecast or weather briefing. Each facility must be analyzed separately to the fullest extent and then used in conjunction with all other information in the weather station to prepare an adequate and accurate forecast or briefing.

It is often the general practice among pilots, and even some of the less experienced weather officers, to glance at a surface synoptic chart and try to plan a flight or make a forecast from this information alone. Since it is understood that the surface synoptic chart may be as much as 6 hours old and that it is impossible to prepare a good forecast from surface data alone, it is reasonable to assume that this type of planning in forecasting is inadequate.

In normal flight operations, it should never be necessary for a pilot to prepare his own weather briefing for any flight, but a good basic understanding of the forecaster's method is extremely helpful to the pilot. The remainder of this section is devoted to a demonstration of the manner in which a weather officer might prepare an adequate route forecast.

Assume that a flight has been planned to depart from Davis-Monthan AFB at Tucson, Arizona for Barksdale AFB at Shreveport, La., on or about 1700C, 29 January 1950.

At 1600C the pilot enters the weather office for the usual flight route weather forecast and briefing. Assume that the weather officer is occupied in briefing other flights. The pilot may acquaint himself with the weather situation by following the same sequence used by the forecaster.

ELEMENTS OF A NORMAL FLIGHT FORECAST

In order to prepare an adequate forecast it is necessary that the weather officer understand exactly what the pilot is interested in regarding the weather situation. Below are the main weather phenomena and hazards with which the pilot is most concerned in the course of flight:

1. Fronts en route, intensity and direction of movement, and points at which these fronts will be encountered.
2. Sky condition en route.
3. Visibility for entire route.
4. Turbulence and icing and where expected.
5. Types of special weather phenomena.

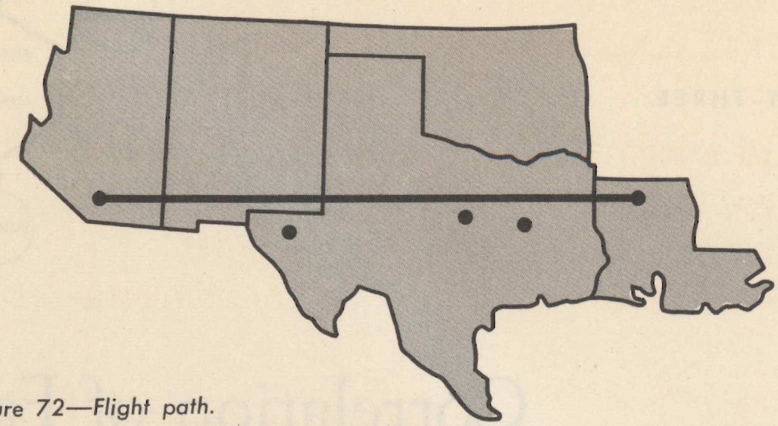


Figure 72—Flight path.

6. Terminal forecast for destination and alternate, usually for ETA plus 2 hours.

7. Direction and speed of winds at flight altitudes, and for surface at terminal.

METHODS OF ANALYSIS

Surface Chart

Since the surface chart is the only facility from which a quick over all synoptic weather picture may be obtained, the forecaster first uses this chart and observes the general positions of highs and lows and areas of weather at the time of this map. He makes special note of the time of *this* map. Since the present time is 1600C, the latest surface chart is the one plotted from observations taken at 1830Z or 1230C. This information, then, is 3 hours, 30 minutes old. Figure 73.

Teletypes

Since the weather shown on the surface chart is old, the forecaster turns to the hourly sequences, making special note of the weather at the stations in the immediate vicinity of the proposed flight path. Now he has brought the surface weather picture up to the present time, Figure 74.

Upper Air

In order to complete his analysis of present weather, it is necessary that the forecaster acquaint himself with the various upper-air data. The latest winds-aloft data available are presented on the 1000C winds-aloft chart. At the present time, (1600C) this information is 6 hours old. The only way the forecaster can make this information current is to project the circulation pattern aloft, ahead six hours and use pilot reports of winds aloft, if available. He now does this. For information regarding stability, moisture aloft, and temperature variations aloft the forecaster consults the adiabatic diagram. The 1000C diagram is available at this time and is 6 hours old.

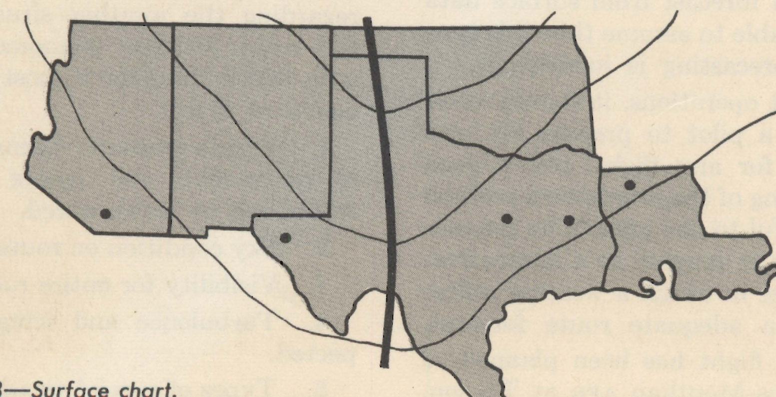


Figure 73—Surface chart.

AW 4 291630 E
FTW—M12 ⊕ 959/68/50 ↘ 32/943
TYR M11 ⊕ 40 ⦶ 10 963 69/53/_ ↘ 30/938
BAD E80 ⊕ ⦷ 15+ 993/73/62 ↑ 32+/950/ E12⊕

Figure 74—1530C Teletype sequence for terminal area.

The fact that adiabatic diagrams are several hours old does not hinder the forecaster significantly because, barring a frontal passage (change in air mass), the characteristics of the air mass remain about the same through at least a 12-hour period, except for changes due to surface heating. These latter can be easily forecasted. (Figure 75).

Forecast

The weather officer is now ready to project this information into the future and prepare his forecast. The most important move now is to decide, analytically, exactly where the main low-pressure centers or storm areas are and the time that this flight will encounter these phenomena and their associated fronts en route. Cyclones, or low-pressure areas, move with the flow aloft. The 700-mb. level generally represents a good average of the flow aloft. Therefore it is used most frequently in forecasting the movement of low-pressure areas and fronts. The approximate time en route for the proposed flight from Tucson to Shreveport will be 5 hours. Assume that at 1700C, a front lies between Tyler, Texas, and Shreveport. The forecaster finds that the general wind flow at the 700-mb. level is about 50 mph from wsw. He moves all systems in this flow with about 90 percent of this speed. By using this method he finds that he can expect the front to be considerably east of the Shreveport area by the time the pilot arrives at this point. Now that he has this determined, the forecaster may safely move all associated weather along with the frontal surface position. Since the front will be east of Shreveport at the estimated time of arrival, a representative sounding will be any radiosonde observation taken in the continental polar air behind the front that morning; and, since the entire flight will be performed in this air mass, this sounding will be a good indication of the stability, moisture content, and freezing level for the entire flight. Where cold air is seen to be moving in aloft behind the cold front, the adiabatic sounding will be modified by the forecaster and the freezing and possible icing level will be lowered. If considerable heating or cooling is expected

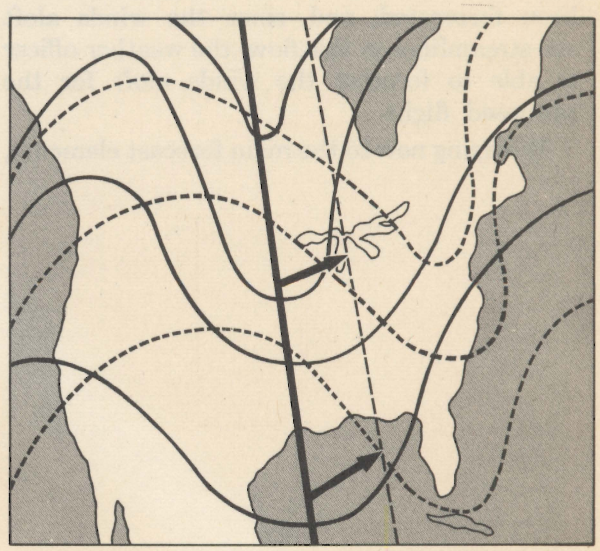


Figure 75—How trough in flow aloft was projected.

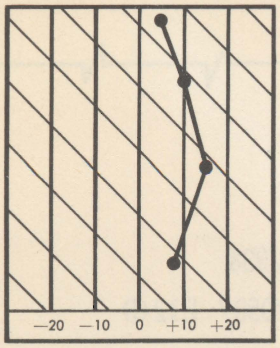


Figure 76—El Paso sounding.

in the surface layers, the diagram will again be modified.

For a forecast of the winds aloft for the proposed flight level, the forecaster will go the upper-air chart closest to this level. For the flight from Tucson to Barksdale the 700-mb. chart would give the 10,000-foot winds for 0900C (that morning). Assume that these winds are circulating about the lower periphery of a trough of continental polar air at the 700-mb. pressure level. The forecaster now observes the position of the trough on 2 or 3 previous 700-mb. charts, and by observing the past movement for any certain period, he is able to project the trough forward a like distance for a similar period in the future. This same process may be worked with each of the troughs and ridges indicated on the chart. Now the new flow at the 700-mb. level has been forecasted, and, since the winds aloft are streamlines in this flow, the weather officer is able to forecast the winds aloft for the proposed flight.

Referring now to the main forecast elements, the weather officer is able to carry out his forecast and briefing for this particular flight. He states that there is a cold front en route at the time of takeoff but that it will be east of Barksdale at the estimated time of landing. By projecting the front and associated weather eastward, he is able to ascertain that the sky condition will be clear at time of take-off, becoming scattered to broken and then overcast as the flight approaches the vicinity of the front.

Since the soundings in the air mass behind the front indicate absolute stability in most cases, the visibility will become restricted after sundown in the area directly behind the front.

There will be no turbulence because of the stable upper-air situation, and the icing level will be at 12,000 feet as shown on the El Paso sounding. (Figure 76).

The terminal will have overcast skies at about 3,000 feet since that is the type of ceiling following closely behind the front. The surface visibility at the time of landing will be 2 miles in light fog, as discussed above, and the temperature will be 60° which will be representative of all surface temperature in that air mass but modified for time of day (evening).

The winds aloft may be forecast directly from the projection of the flow at 700 mb. since this flight will be performed at or near 10,000 feet. The winds will be westerly to south westerly with velocity of 40 knots, increasing to 70 knots in the Dallas vicinity, and decreasing to 50 knots near Shreveport.

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